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TECHNICAL REPORT

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SEQUENTIAL STUDY OF DESERT FLOODING IN THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

by

Chester B. Beaty

University of Montana
Missoula, Montana

January 1968

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts, 01760

Earth Sciences Laboratory

ES-37

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SEQUENTIAL STUDY OF DESERT FLOODING IN THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

by

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Department of Geography, University of Montana
Missoula, Montana

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U.S. Army Materiel Command
U.S. ARMY NATICK LABORATORIES
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FOREWORD

In 1956-57 the Quartermaster Research and Engineering Command sponsored a study of desert flooding and the circumstances under which it is likely to be a hazard to military activities in and near desert mountains. During the course of that study, which was conducted in the White Mountains of California and Nevada, Dr. Chester B. Beaty (then a graduate student at the University of California) documented the conditions at that time by numerous sketch maps and photographs. Ten years later, Dr. Beaty returned to the White Mountains under contract DA19-129-AMC-987(N) with the Army, to determine the extent and nature of landform changes that had occurred during the intervening decade. The sequential study reported here afforded a rare opportunity to test and verify the principles of site safety that were established by the earlier investigation, and to assess the probable frequency of occurrence of damaging floods and debris flows in such an area.

Appreciation is expressed for the cooperation of the following organizations and individuals who assisted the field investigation in various ways: Ranger Harold McElroy and other personnel of the U.S. Forest Service at Bishop, California; Dr. F. Duane Blume, Resident Physiologist, White Mountain Research Station, and other personnel of the University of California high altitude laboratories; the Chalfant Press, Bishop, California; the Department of Geography, University of California, which made available aerial photographs of the White Mountains area; and the U.S. Army Aviation Test Activity, Edwards Air Force Base, California, which made possible several helicopter flights over the area for photographic purposes.

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ABSTRACT

A field study of flood conditions in the White Mountains of California and Nevada was carried out during the period September 1966 to August 1967. The investigation was a follow-up to a similar study conducted in 1956-57. The purpose of the current study was (1) to determine what changes, if any, flooding had produced in the area during the decade 1957-66, (2) if possible, to observe flooding in action and record its effects, and (3) to test and attempt to verify principles of flooding behavior and site safety established by the investigation of 1956-57.

Flooding during the decade 1957-66 has produced significant changes in parts of the White Mountains landscape. One minor and two major debris flows occurred during the period, and minor snowmelt flooding was frequent.

Flooding observed during the contract period was of the three types known to occur in the study area: Wintertime, Snowmelt, and Cloudburst floods. Floods were observed in December 1966, May-June 1967, and July-August 1967. No debris flows developed during any of the episodes of flooding.

In the study of 1956-57 it was found that three physiographic characteristics influence flooding behavior in a desert stream system: (1) trunk canyon profile; (2) amount of debris on floor of trunk canyon; (3) width of lower canyon and canyon mouth. The most dangerous canyons are steep, narrow, and floored with 5 to 15 feet of unconsolidated debris. The area of greatest flooding danger on a desert alluvial fan is a radial zone extending from the apex toward the margin and flanking and including the active channel.

The observed and reconstructed behavior of floods in and near the White Mountains during the period 1957-67 was in accord with the indicated principles, and it is concluded that these principles are valid.

SEQUENTIAL STUDY OF DESERT FLOODING IN THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

INTRODUCTION

1. Purpose of Study

During the period July 1956 to December 1957 the author and Professor J. E. Kesseli, of the Department of Geography, University of California, Berkeley, conducted a field study of desert flooding in the White Mountains of California and Nevada. At that time I resided in the area for 15 months and observed at firsthand minor snowmelt flooding and the results of two small cloudburst floods. No major floods were seen in action, although the physiographic effects of fairly recent major flooding and debris flows were intensively examined. The results of that study were published in 1959 as "Desert Flood Conditions in the White Mountains of California and Nevada" (Kesseli and Beaty, 1959).

The present study was undertaken, a decade later, with the purpose of re-examining the White Mountains area and adjacent desert regions to discover if significant flooding and associated morphologic changes had occurred during the intervening years, and, if they had, to document these changes photographically and cartographically. Since it was hoped that active flooding might be observed during the study period, I lived in Bishop, California from September 1966 to August 1967.

The goals of the present study were as follows:

1. To conduct a field investigation of desert flooding and associated landforms in the White Mountains of California and Nevada, with special attention to the western slope of the mountains, to determine the effects of intensive rainfall that may have occurred during the past 10 years on the landforms, landscape, and land use of the area as a guide in protecting men, equipment, transportation routes, and storage facilities from flood hazards in desert regions.

2. To test the various hypotheses relating to the differences in magnitude of flooding hazard at different canyons, on the basis of the effects of floods that may have occurred since the appearance of the area was documented in 1956-57.

3. To study, during the contract period, the frequency, occurrence, and duration of rainfall and floods and their areal extent within the study area, and relate these occurrences to

size and configuration of the catchment areas.

4. To determine, to the extent feasible, the extent and effect of flooding during the past 10 years in other desert regions near the White Mountains.

5. To revise and evaluate, to the extent indicated by results of the study, the conclusions set forth in Technical Report EP-108, "Desert Flood Conditions in the White Mountains of California and Nevada" (1959).

2. Choice of Area

The White Mountains were selected for the present study for the following reasons:

1. They had been carefully investigated 10 years ago, and I was familiar with their physiographic features and climatic characteristics.

2. It was established by the study of 1956-57 that the White Mountains had experienced serious flooding in recent years, particularly on the western side.

3. The range is considered to be reasonably representative of other high desert mountains, both in the United States and in other parts of the world.

4. The University of California maintains two laboratories on the crest of the range, at which year-round weather observations are taken; climatic data from these stations could be of considerable value in estimating precipitation intensities and durations producing flooding.

5. Finally, and perhaps most importantly, I had documented photographically the appearance of major drainage systems within the range and the flanking alluvial fans during the period of study in 1956-57; this photographic record represented a tool of potentially great utility in evaluating landscape changes that may have occurred within the past 10 years.

In short, a follow-up study of the White Mountains, a decade after the first investigation, would provide a unique opportunity for an objective examination of contemporary landscape alteration in a desert environment. Equally important, it would make possible a practical re-evaluation of principles of site safety and land use established by the study of 1956-57.

3. Methods of Investigation

As was the case during the study of 1956-57, four different methods of investigation were employed during the present study:

1. Published records of flooding events during the decade 1957-66 were obtained from a review of local (i.e., Bishop, California) newspaper files. The Chalfant Press of Bishop again made available files of the Inyo Register and other regional weekly newspapers printed at its plant. Only a relatively few and minor floods during the period of interest were mentioned in the local papers.

Climatic records from U. S. Weather Bureau stations within the general area of study were consulted to determine if any unusually heavy rains had fallen at official stations during the decade 1957-66. Several fairly high rainfall totals were noted, but only one or two of these seem to have been accompanied by flooding of sufficient magnitude to have been reported in the local press or to have been clearly remembered by residents of the area.

2. In order to supplement the comparatively widespaced network of official weather stations within the study area, I installed a number of rain gages - both recording and non-recording - in selected locations in the White Mountains and visited these after periods of precipitation during the contract period. In at least two cases of flooding, the supplemental gages provided precipitation data that otherwise would not have been available, data that shed considerable light on the question of just how much precipitation is necessary to produce flooding of a given intensity in the study area. These cases are discussed in detail in a later section of this report.

Precipitation records for the period of field study (September 1966 to August 1967) are given in the Appendix.

3. I interviewed residents of the area to add detail to the few newspaper accounts of floods and to discover any other floods that may not have been reported in the local press. Unfortunately, the most spectacular flood and debris flow of the decade occurred at night, so that a number of potential eyewitnesses were, in fact, earwitnesses, hearing, rather than seeing, a major debris flow in Montgomery Creek, east of Benton Station, California (now named simply Benton on the 1962 U.S.G.S. Benton 15-minute topographic quadrangle). This debris flow is described in Part II of this report.

4. The most productive method of investigation was field examination of drainage systems and alluvial fans which had sustained significant flooding during the 1957-66 decade. Photographs of the area taken in 1956 and in 1957 greatly helped to evaluate flooding effects and physiographic changes. It has been possible to document with some

precision the morphologic effects of two impressive debris flows that occurred during the decade. Admittedly, if I had known in 1956-57 what I know today, the photographic documentation would have been even more complete, but I feel that the record here presented is of value. Additional pictures have been taken so that possible future study in the area may benefit from more complete photographic coverage.

PART I

GEOGRAPHIC AND GEOLOGIC SETTING

Since the area of interest to this study was described in detail in the report of the earlier investigation (Kesseli and Beaty, 1959, pp. 5-24) and has been dealt with at length in numerous other publications (see, for example: Knopf, 1918; Blackwelder, 1931, 1934; Anderson, 1937; Gilbert, 1938; Beaty, 1960, 1963; Pace, 1963; Powell, 1963; Hall, 1964; Pakiser et al, 1964; Bateman, 1965; Jones, 1965; LaMarche, 1965; Lustig, 1965), its description in the present report will be limited to an account of its major climatic characteristics and a brief mention of what are judged to be the most important morphologic features. Emphasis will be placed on those aspects of morphology I believe to be of significance in considering flooding and flooding hazards.

1. Climatic Characteristics

The White Mountains area is generally a region of aridity and semi-aridity. Owens Valley on the west and Fish Lake Valley on the east of the range are dry, with an average annual precipitation of less than 6 inches on the floors of both valleys. Even the higher parts of the White Mountains receive only moderate precipitation, with yearly totals at elevations above 10,000 feet averaging between 10 and 20 inches. In Owens Valley and along the crest of the White Mountains there is a pronounced California coastal precipitation regime; that is, much of the rain and snow comes during the cooler part of the year, released from migrating low-pressure storm systems moving from west to east. Summertime precipitation falls primarily from thunderstorms, which occur sporadically throughout the general area in that season. East of the White Mountains, on the floor of Fish Lake Valley and in adjacent parts of western Nevada, precipitation tends to be somewhat more evenly distributed throughout the year, with summertime thunderstorm amounts approximating wintertime cyclonic amounts.

In all parts of the area it has been the infrequent torrential summer cloudbursts that have produced the greatest measured amounts of rain in brief periods of time and also, as would be expected, the most spectacular and dangerous flooding. Estimated and measured short-time rainfall intensities of several inches per hour have been fairly common during the historical period in the region, and in one case about 8-1/4 inches of rain fell in the northern White Mountains in slightly more than 2 hours (Kesseli and Beaty, 1959, p. 18-24). It has long been appreciated in this desert area, as in others throughout the world, that precipitation records from valley floor weather stations (and most of the weather stations in the White Mountains area are in the lowlands) are of little value in estimating rainfall amounts and intensities in the flanking highlands. The White Mountains are unique in this respect in that

year-round weather observations are made at the two University of California research stations along the crest: Crooked Creek Laboratory, elevation 10,150 feet, and Mount Barcroft Laboratory, elevation 12,470 feet. Occasional short-time records have also been kept during the summer months at the Summit Laboratory atop White Mountain Peak, elevation 14,246 feet.

Seasonal temperature variations throughout the study area range from summertime afternoon highs of more than 100°F. on valley floors to wintertime lows of -15 to -30°F. along the crest of the White Mountains. A strong climatic seasonality is evident in the lowlands of the region, but extreme fluctuations above and below long-time temperature means are rare.

Strong northerly and southerly winds are common in the area, both along the crest of the range and in the adjacent valleys. During the winter and spring months, strong westerly winds aloft, flowing over the Sierra Nevada, create the "Sierra Wave" in Owens Valley and along the western flank of the White Mountains, for which the region is internationally known to sailplane pilots.

Average monthly and annual temperature and precipitation values for a number of U.S. Weather Bureau stations within and adjacent to the area of study are given in Table 1. Location of the stations is indicated on Figure 1. Most of the stations listed (some of which are inoperative today) have periods of record ranging from 15 to 30 years; weather observations have been taken at Bishop, California for about 60 years.

2. Geologic and Physiographic Characteristics

The principal features of the geology of the White Mountains are comparatively simple. Basically, the range consists of a granitic core partially overlain by masses of sedimentary, metasedimentary, metamorphic, and volcanic rocks. Granitic rocks outcrop along the crest and much of the flanks in the northern third of the mountains; the zone of granitic outcrop swings to the eastern side of the range in its southern part. In the southern half of the range, sedimentary, metasedimentary, and metamorphic rocks underlie the crest and western side.

In terms of gross geologic structure, the White Mountains appear to be a large, tilted fault block, in which relative tilting has been toward the east (Pakiser et al, 1964, p. 54-55; Bateman, 1965, p. 170-173). Accordingly, the western flank of the range is considerably steeper than its eastern counterpart, with precipitous slopes and a relief of 6,000 to 9,000 feet in horizontal distances of only a few miles. Steep slopes characterize parts of the eastern side of the mountains, but average inclinations are generally much lower than those on the west.

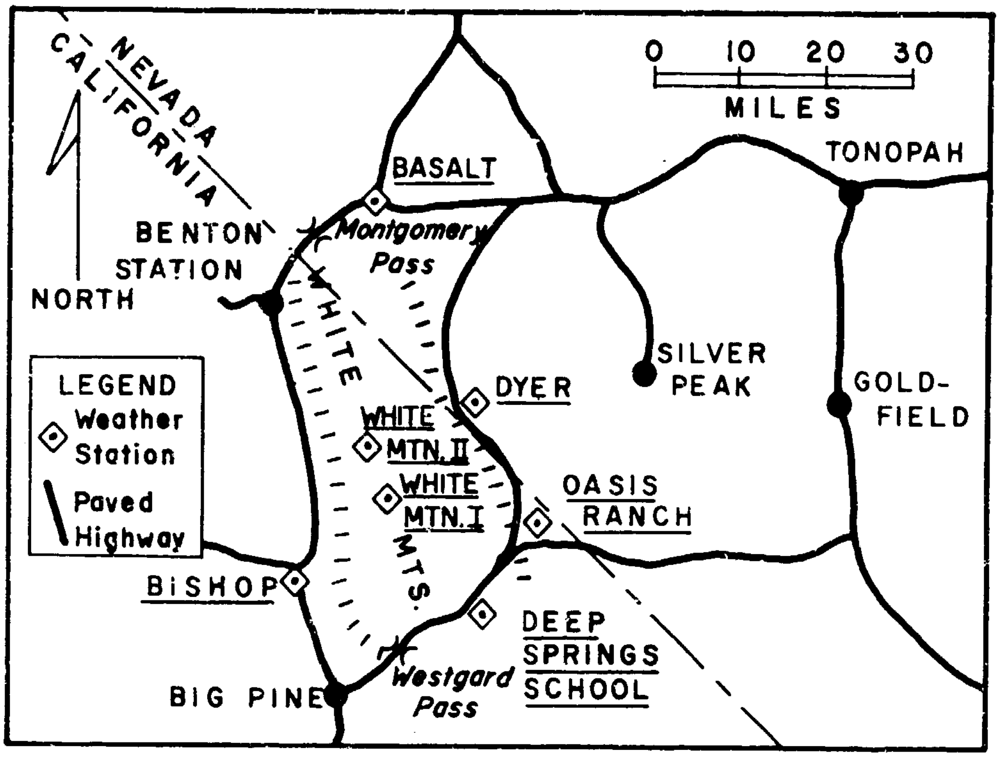


Figure 1. Location of the White Mountains, showing U.S. Weather Bureau stations within and near the study area.

More than 20 major drainages are found along the western flank of the range, many of which have extremely steep and narrow trunk canyons. Average gradients of trunk canyon floors in west-side catchment basins are high, more than 1,000 feet per mile in most places and nearly 2,000 feet per mile in a few stream systems. In contrast, the fewer and larger east-side drainages are generally distinguished by much gentler average trunk-canyon gradients; these vary from 600 to 1,000 feet per mile. In their 1956-57 field study of the White Mountains, Kesseli and Beaty (1959, p. 7-8) differentiated between two contrasting trunk canyon profile types; the Falls Canyon type, extremely steep to mouth of canyon, and the Middle Creek type, steep in headwater area but relatively gentle in lower trunk canyon. As was pointed out then (Kesseli and Beaty, 1959, p. 90-92), canyon profile is considered to be a most important factor in evaluating the flooding potential of a given stream system. As will be discussed later in this report, localization of significant flooding in the White Mountains during the decade 1957-66 strongly supports conclusions regarding the effect of canyon profile reached during the study of 1956-57.

TABLE I

AVERAGE MONTHLY AND ANNUAL TEMPERATURE AND PRECIPITATION FOR STATIONS WITHIN AND ADJACENT TO STUDY AREA
Temperatures in °F., precipitation in inches

Station	Elevation		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Av.	Annual Total
Bishop	4,108	Temp.	37	41	48	55	63	70	77	74	68	57	46	39	56	
		Prec.	.99	.98	.55	.46	.20	.09	.12	.12	.19	.43	.53	1.18		5.84
Deep Springs School	5,225	Temp.	28	34	42	52	59	67	71	70	66	54	42	30	52	
		Prec.	.71	.29	.63	1.11	.43	.15	.36	.11	.26	.12	.26	.77		5.45
Dyer	4,975	Temp.	29	36	40	50	58	64	73	70	63	53	40	32	51	
		Prec.	.41	.33	.19	.78	.36	.11	.42	.09	.28	.14	.07	.36		3.22
*Oasis Ranch	5,106	Temp.	29	34	41	50	55	64	70	68	60	49	38	29	49	
		Prec.	.66	.57	.35	.41	.47	.26	.40	.41	.28	.27	.27	.42		4.77
*Basalt	6,350	Temp.	29	33	38	48	54	61	70	68	62	50	39	31	49	
		Prec.	.41	.58	.34	.66	.54	.21	.49	.26	.25	.55	.51	.83		5.39
White Mtn I	10,150	Temp.	20	21	22	30	36	47	52	51	46	37	29	24	35	
		Prec.	1.36	2.00	1.09	1.21	1.60	.22	1.42	.63	.50	.60	.93	.98		12.54
White Mtn II	12,470	Temp.	15	14	15	22	26	38	45	44	39	30	23	19	28	
		Prec.	1.55	1.78	1.37	1.48	2.44	.44	1.42	.93	.72	1.19	1.16	1.06		15.54

Note: Monthly and annual temperatures have been recorded to the closest whole degree.

*No longer in operation.

On both sides of the range, alluvial fans are well-developed and conspicuous elements of the larger landscape. Fans along the western flank are 2 to 3 miles in radius, with elevation differences of 600 to 1,200 feet between perimeters and apexes. Those in northern Fish Lake Valley, on the east, tend to be broader, measuring 4 to 6 miles in radius. Although elevation differences between apexes and perimeters are about the same on the east-side fans as they are on the west, their greater radial extent gives to them somewhat more gentle surface slopes.

The White Mountains alluvial fans appear to be built of superposed debris-flow deposits (Beaty, 1963). Surface features and the limited amount of evidence of structure and composition at depth clearly indicate that at least the upper parts of the fans represent the results of repeated debris-flow deposition. The most recent major floods in the range have been accompanied by massive rubble flows, by which large volumes of material have been added to the fans (Kesseli and Beaty, 1959, p. 34-51). In at least two cases, serious flooding during the decade 1957-66 was of the debris-flow type; these floods and their concomitant debris flows are described in detail in Part II of this report.

3. Summary

The White Mountains, although higher than most, are otherwise typical of the arid to semi-arid ranges of the American Great Basin. Lying in the rain shadow of the adjacent Sierra Nevada, they receive much less moisture than their elevation would lead one to expect. Yet a significant part of the yearly precipitation comes from summer thunderstorms, and it is as a result of the isolated but potent cloudburst that most of the major and potentially dangerous flooding occurs. Great relief, steep and sparsely vegetated slopes within drainage basins, and a climate characterized by occasional summertime thunderstorms combine to make the White Mountains and the adjacent valleys an excellent area in which to study the geomorphological effect of desert flooding and its effect on human activities.

PART II

FLOODING IN THE WHITE MOUNTAINS

1. Introduction

A fairly complete investigation of flooding during the historical period in the White Mountains was made in the course of the study of 10 years ago (Kesseli and Beaty, 1959, p. 27-34). To establish the flooding pattern, the authors examined newspaper files and consulted long-time residents of the area. The newspaper record goes back to 1872, although a few years are missing during the early part of the period. As was noted, it can hardly be expected that all floods taking place in and near the White Mountains would be recorded by the journals. Nevertheless, we believe the record to be based upon a satisfactory sample and consider the generalizations derived from it to be valid. Two significant facts emerged from that investigation:

1. There has been a notable increase in <u>reported</u> floods in the White Mountains region during the last several decades.

2. There has been a marked concentration of floods in the area during the <u>summer</u> months, particularly July and August.

As was noted in the earlier study, the detectable increase in reported floods over the last 30 to 40 years has coincided with an increase in population in the area, an extension of the highway network, and an increase in the number of vehicles using the road system. The results might reasonably have been anticipated: Flooding has increasingly interfered with human activity and accordingly has been more frequently reported in the press of the area. There is little, if any, evidence in the available weather records to suggest that climatic factors have accounted for the increase in reported floods. In other parts of arid America, similar trends in flooding, as reflected by newspaper accounts, have been noted by other investigators (Woolley, 1946).

So far as seasonal distribution of flooding is concerned, the historical record shows clearly that floods in the White Mountains area (and in adjacent parts of the American Great Basin as well) occur predominantly in the summer months (Figure 2). As the graphs indicate, about 60 percent of the recorded floods in the area of interest to this study have taken place in July and August, and most of them have resulted from intense thunderstorm rain. This pattern is probably representative of many or most of the earth's desert regions in which summertime thunderstorm activity is an important element of the climate. During the decade 1957-66, flooding in the White Mountains area in general conformed to the seasonal pattern suggested by the historical record; that is, most of the reported floods occurred during the warmest part of the year.

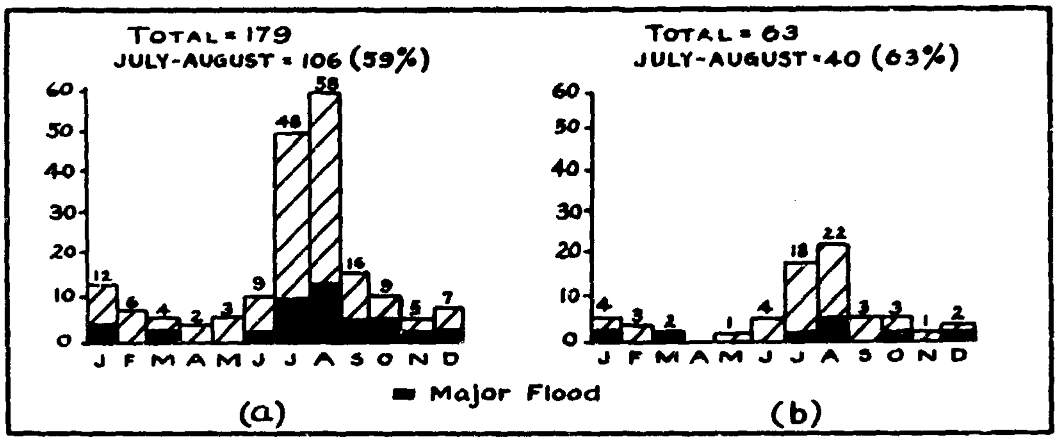


Figure 2. Flooding occurrence for each month in (a) an area bounded by lines joining Mono Lake, California; Tonopah, Nevada; Baker, California; and Mohave, California; and (b) the White Mountains alone. Period of record: 1872-1957.

The study of flooding undertaken 10 years ago also showed that floods in the White Mountains area can conveniently and realistically be arranged into three seasonal groups:

(1) The true Cloudburst Floods, occurring almost invariably in summer and produced by thunderstorm rain.

(2) The Snowmelt Floods, occurring in late spring and early summer and occasionally augmented by thunderstorm rain.

(3) The Wintertime Floods, taking place primarily as a result of unusually heavy frontal rains at lower elevations, accompanied by snow at higher elevations.

Flooding of all three types occurred in the area during the period of field study for this report (September 1966-August 1967) and is discussed in a later section.

Of interest in the context of the present study is the estimate of flooding frequency in the White Mountains arrived at as a result of the investigation of 1956-57. Based upon newspaper accounts alone, an estimated frequency of 6 to 8 floods per decade, of which 1 to 3 could be classified as "major" or "serious", was suggested (Kesseli and Beaty, 1959, p. 34). Consideration of the flooding history of the White Mountains during the past 15 to 20 years, for which much better records are available, necessitates a refinement of these figures; as pointed out by Kesseli and Beaty (1959, p. 88-89), "...the experience of this period...indicates a flooding possibility of as many as 12 to 15 floods per decade, of which

5 may be of major proportions." During the decade 1957-66, as will be discussed later in this report, there were 3 or 4 floods of major proportions, with perhaps 8 to 12 minor floods. It seems safe to assert that estimates of flooding frequency based upon newspaper records and supplemented by more complete information for recent decades appear to have considerable validity, at least for the White Mountains area.

2. Floods During the Decade 1957-66

I found reasonably good information on two significant floods with debris flows during the period 1957-66; I learned of a third flood with a minor debris flow, but I could not get many specific facts about this event. Unfortunately, ownership of several of the ranches on both sides of the White Mountains has changed in the past 10 years, and people who may have been in excellent positions to make first-hand observations no longer reside in the area. Nevertheless, by using limited interviews, field observations, and comparing "before" and "after" photographs, I could satisfactorily reconstruct the two larger floods and debris flows.

a. Sparkplug Canyon, May or June, 1958 (Named "Jeffrey Mine Canyon" on the 1962 U.S.G.S. 15-minute White Mountain Peak topographic quadrangle)

Sometime in late May or early June 1958, a major debris flow developed in the lower end of Sparkplug Canyon and poured onto the adjacent alluvial fan (Figure 3). I could not determine precisely the date on which this debris flow occurred. The owner of the nearby White Mountain Ranch, across part of which water and mud flowed, was unable to recall the exact day on which the debris flow took place, and diligent search for other possible eyewitnesses was fruitless. What is highly unusual about this debris flow is that it evidently was generated by snowmelt runoff rather than by thunderstorm rain. Although somewhat special circumstances seem to have existed in the case of this debris flow, if it was produced by snowmelt runoff then it must be considered a "first" for the White Mountains area, since I know of no other instance where melting snow has provided sufficient surface runoff to start debris flowing on such a scale.

(1) Weather Preceding Debris Flow

The University of California's Mount Barcroft Laboratory operates the weather station closest to Sparkplug Canyon. The Barcroft laboratory is at an elevation of 12,470 feet and is about 4-1/2 airline miles southeast of the upper part of the drainage system. Elevations within the Sparkplug Canyon catchment basin are generally less than 10,000 feet; the mouth of the canyon lies at an elevation of roughly 5,300 feet. It is apparent that weather data from the Barcroft Station are not necessarily representative of the Sparkplug Canyon drainage basin. However, in the absence of data from within the basin itself, I had to rely upon the available record.

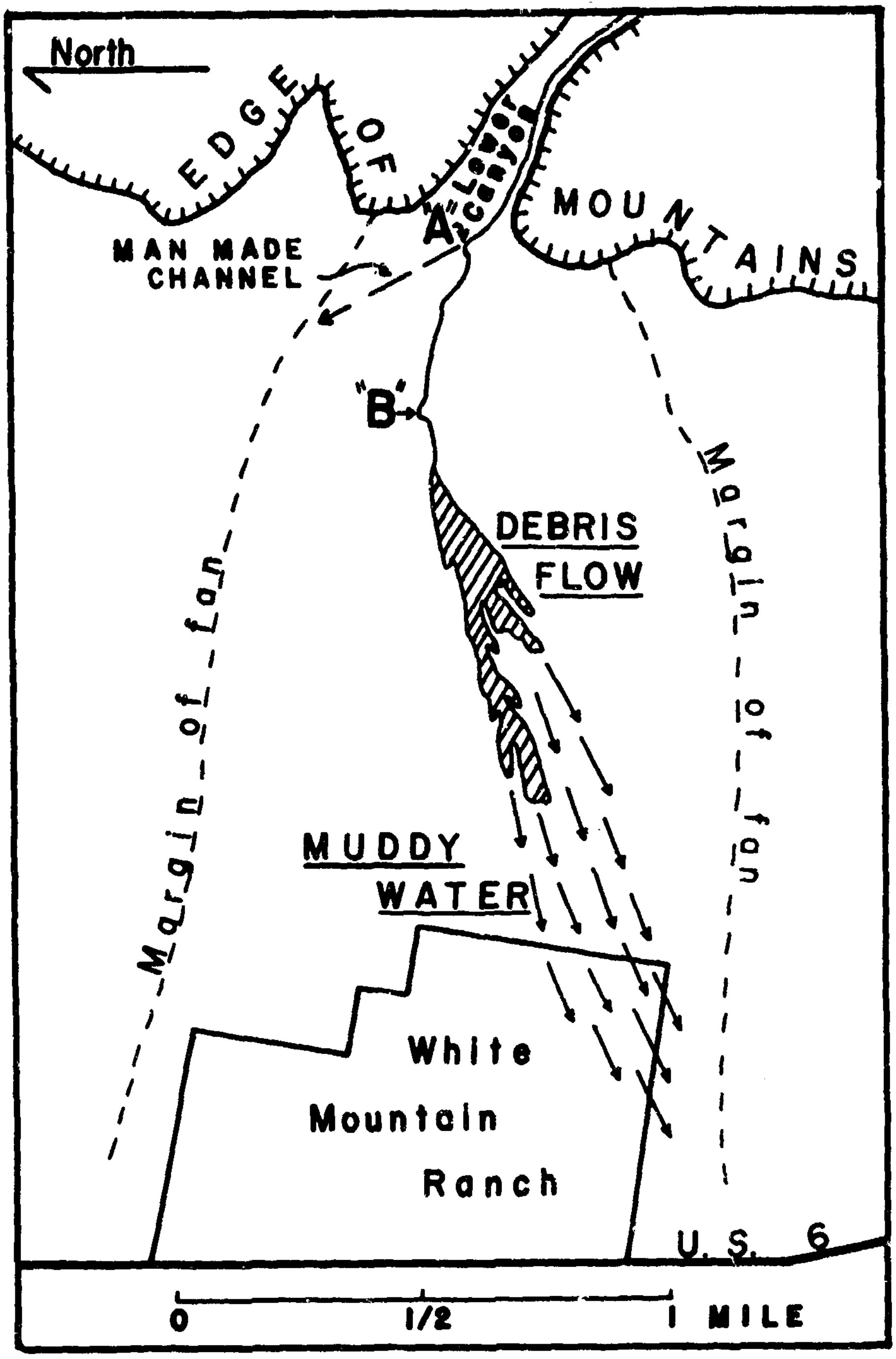


Figure 3. Map of Sparkplug Canyon fan showing deposits of 1958 flood and location of White Mountain Ranch. Traced from an aerial photograph taken in 1962. "A" indicates point of diversion of man-made channel. "B" indicates location where minor amounts of debris spilled from active channel.

The winter of 1957-58 was comparatively wet at Mount Barcroft. This station received about 150 inches of snow from October 1957 to May 1958, compared with a 10-year average of 135 inches for the period (Pace, 1963). Average snow depths at the station from February through May 1958 were well above the 10-year means, with a maximum of 54 inches measured in April. The average May snow depth was nearly 23 inches, almost twice the 10-year mean for that month. The Barcroft record suggests that a comparatively deep snowpack was present in the range in late spring 1958, at least along the crest.

Temperature records from the Barcroft laboratory for this period are also of interest. May 1958 appears to have been a relatively warm month, with monthly mean, maximum, and minimum temperatures well above the 10-year averages. In contrast, June 1958 was noticeably cooler than the 10-year mean (Pace, 1963).

The record at Mount Barcroft indicates that the Sparkplug Canyon flood and debris flow probably occurred in May 1958, most likely late in the month. At least weather data from this station near the crest of the range do not rule out the possibility of the occurrence of voluminous snowmelt runoff in that month.

(2) Eyewitness Account

I found only one eyewitness to this flood and debris flow, the owner of the White Mountain Ranch. Since flooding occurred during the night, sometime after midnight, the witness, Mrs. Margaret Pillsbury, did not actually see movement of fluid debris on the Sparkplug Canyon alluvial fan. However, she was made aware of flooding because water and mud were flowing over parts of the ranch to depths of 1 to 2 feet, piling up against obstacles and entering several open outbuildings, including a structure containing a small hydro-electric generating plant. The latter was put out of action by the flood when more than 2 feet of mud partially buried some of the equipment.

At dawn the fresh debris flow was noticed on the alluvial fan above the ranch. There was no indication of movement of the debris itself, although a stream of muddy water was coursing down the center of the flow and onto part of the ranch (Pillsbury, M., personal communication, 1967). This muddy water continued to flow for a day or two, after whi. the runoff was diverted near the apex of the alluvial fan.

About a week after the initial flooding and debris deposition, a second rush of water came from Sparkplug Canyon, again reaching the White Mountain Ranch in the early morning hours (Pillsbury, M.). On this occasion there evidently was no debris flowage from the lower canyon onto the fan. As in the first instance, muddy water continued to flow across parts of the ranch for a day or so, until a second diversion was made.

It should be stressed that in both cases no precipitation occurred that might have at least partially contributed to the flooding (Pillsbury, M.). Evidently all of the water which came from Sparkplug Canyon was of snowmelt origin. Weather during the episodes of flooding was warm and dry, "much warmer than usual", according to the witness' best recollection.

(3) Possible Explanation of Origin

As noted above, this particular episode of flooding and debris flowage is remarkable in that it was apparently not produced by thunderstorm precipitation. Although snowmelt flooding has been - and still is - a fairly common phenomenon in the White Mountains, very few, if any, of the recorded and remembered snowmelt floods have been accompanied by major debris flows. In this case it is necessary to account for a volume of water in the Sparkplug Canyon drainage system sufficiently great to induce movement of a large mass of unconsolidated debris.

Observations of snowmelt flooding in many parts of the world, including the White Mountains (Kesseli and Beaty, 1959, p. 60-68; also, discussion of flooding in May and June 1967, in a later section of this report), have indicated conclusively that large variations in flow typically occur in many stream systems during a period of active melting. Especially if the weather is warm and dry there will be marked fluctuations in discharge during the day-night-day cycle, with maximum runoff reaching lower canyons and alluvial fans around midnight or in the early morning hours. Although a considerable volume of snowmelt water may flow from an individual drainage basin, it tends to be released relatively gradually, and the period of high average discharge may last for a week or 10 days. In drainage systems which have recently been subject to major flooding and debris flows, the diurnal discharge cycle may fluctuate widely (see Kesseli and Beaty, 1959, p. 61-67). In contrast, streams which have not flooded severely for many decades, and which therefore retain thick accumulations of alluvium and colluvium on trunk canyon floors, tend to undergo only a gradual and prolonged rise and fall in discharge, the masses of unconsolidated debris in their trunk canyons acting as very effective "sponges" for the additional water released by the large amount of snowmelt.

In the case of Sparkplug Canyon, which has experienced at least moderate flooding several times within the historical period, it is difficult to understand how a volume of water sufficiently large to have produced the debris flow on the alluvial fan could have accumulated from snowmelt runoff alone. The trunk canyon is steep from its uppermost point almost to the mouth, with an average gradient of nearly 1,400 feet per mile. There are no natural basins or sumps along the course of the trunk canyon in which sizable amounts of meltwater could have been ponded. It is reasonable to suppose that this drainage system would undergo fairly significant fluctuations in discharge during a period of

active snowmelt in its upper reaches, but it is hard to visualize a natural situation in which runoff capable of producing a debris flow could have developed under the conditions that apparently prevailed in the spring of 1958.

I believe that the probable cause of the debris flow is related to man's interference with natural conditions. At some time in the past, a diversion channel was cut near the apex of the alluvial fan to lead excessive runoff to its northern margin (point "A", Figure 3). This artificial channel branches from the present active channel at a place where the latter makes a sharp bend to the left, or south. Although Sparkplug Canyon supports a perennial stream in its upper basin, there is normally no surface flow in the lower canyon or on the alluvial fan. However, there has certainly been major flooding that threatened the White Mountain Ranch since the area was settled, otherwise the diversion channel would not have been made. Apparently in late May or early June 1958 the active channel became plugged or dammed at or just above the point of diversion. I don't know how this postulated damming occurred. Mrs. Pillsbury suggested that several large boulders embedded in the walls of the active channel were undercut and caved into the channel, forming a nucleus, so to speak, around which a temporary debris dam formed. The undercutting presumably was done by the first surges of snowmelt runoff, which, until the debris dam came into existence, had been successfully diverted into the man-made channel. If damming of this sort did occur - and it has happened naturally on other parts of the Jeffrey Mine Canyon fan and on other White Mountain fans - then at least one can picture a situation in which a large volume of water could have accumulated. Since in both instancesof flooding the events occurred in the early morning hours, evidently snowmelt runoff was the source of the water.

I assume that temporary debris dams did form at or near the point of diversion, that their formation was at least in part a result of man's alteration of the natural active channel, that runoff from melting snow was ponded and backed up in the lower canyon until the dams were breached or overtopped, and that large volumes of water rushed through and out of the lower canyon, scouring its floor and producing, in the first instance of flooding, the conspicuous deposit of fresh debris on the central part of the fan. There seems to have been no other way in which a sufficiently large volume of water could have been collected.

(4) Morphologic Effects

The most outstanding and readily recognizable effect of the Sparkplug Canyon flood was deposition of a sizable mass of fresh debris on the alluvial fan (Figure 4). This debris flow has most of the morphologic characteristics of comparable recent flows on adjacent White Mountain fans. As explained above, it is believed that the flow was generated by the sudden release of a large volume of water temporarily ponded

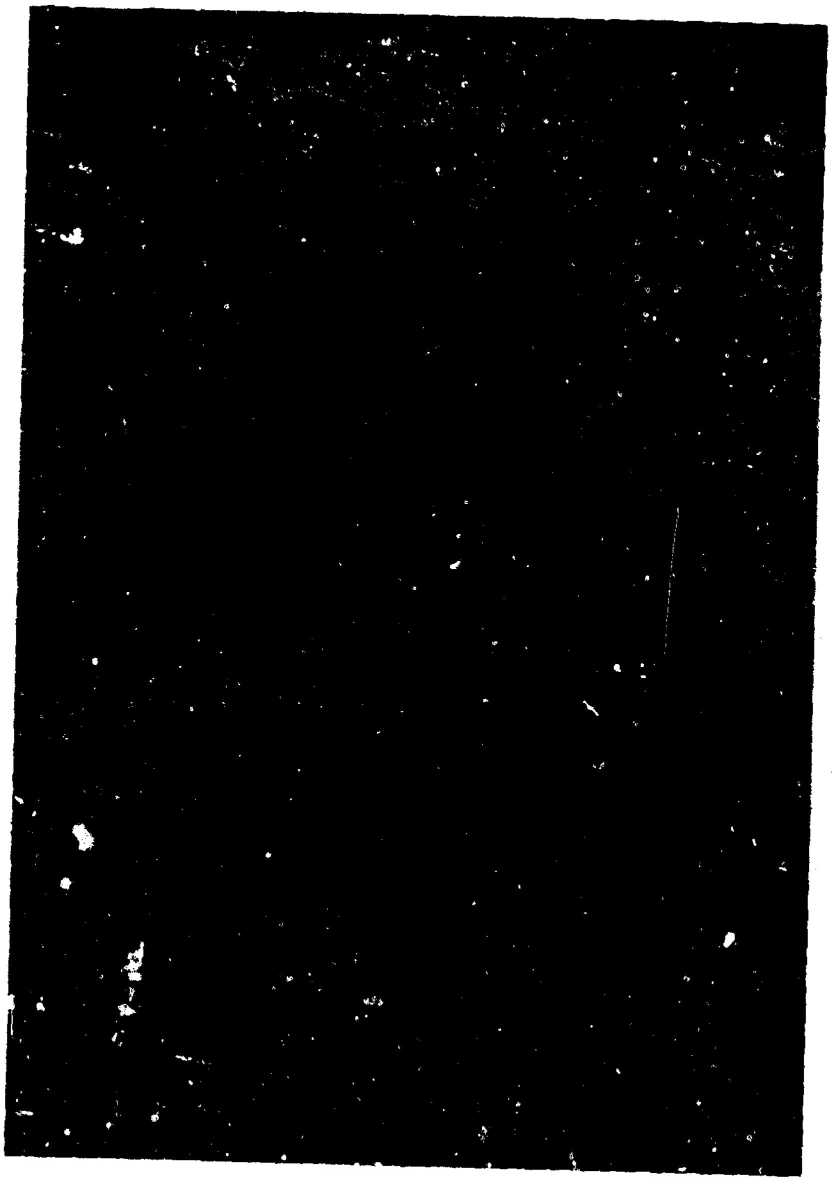


Figure 4. Oblique aerial view of 1958 debris flow on Sparkplug Canyon alluvial fan.

in the lower canyon of the drainage system. Although no one observed the debris flow in action, an accurate reconstruction of events seems possible, based primarily on geomorphologic evidence on the alluvial fan and in the lower part of Sparkplug Canyon proper.

The surface morphology of the flow strongly suggests that the debris moved as a single, relatively coherent mass, rather than as a series of waves or surges, as has been the case with other White Mountain debris flows (see Kesseli and Beaty, 1959, p. 38-42). There are no recognizable overlapping layers of debris on the surface of the deposit; much of it is comparatively smooth, as though deposition occurred at more or less the same time throughout its entire extent, although in places post-depositional erosion has cut shallow channels (Figure 5 A and B). As the photographs clearly show, the mass of debris split into a series of individual lobes below the point at which it began spilling out of the active channel. Movement of the central thread of fluid debris seems to have been controlled by the position of the active channel, down which the bulk of the material flowed. The smaller distributary lobes followed elongated depressions on the surface of the fan, flowing downfan until slowing down and loss of water by percolation stopped them.

The margins of the debris flow are sharp and distinct in most places, standing at fairly steep angles (25 to 35°) or overlapping small shrubs or boulders. Insufficient time has passed since deposition occurred for surface washing significantly to have altered most parts of the flow.

Thickness of the fresh debris ranges from 4 to 6 feet at the point where spilling from the active channel began, to less than 1 foot along the lower margins. Average thickness for the deposit as a whole is 2 to 2-1/2 feet.

As has happened in the past in the White Mountains and other parts of arid western America, flooding in the form of running water followed debris deposition on the Sparkplug Canyon alluvial fan. The high water followed approximately the old active channel over most of the debris deposit, cutting completely through the fresh material and exposing a narrow strip of the older fan surface through the center of the flow (see Figure 5 A and B). It was primarily this high-water flooding that was responsible for depositing 1 to 2 feet of silt on parts of the adjacent White Mountain Ranch.

I can only guess about the source area for the material in this debris flow. Probably much of the unconsolidated rubble came from the floor of the lower mile of canyon. This is indicated by the fact that a road across the channel floor about half a mile above the canyon mouth was completely cut away to a depth of 4 to 6 feet below the "ends" on both sides of the channel (Figure 6). It also seems probable that some material came from the floor of the trunk canyon higher in the drainage system, since at one place about 1-1/2 miles above the mouth of the canyon a man-made trail across the floor of the channel has been scoured out to

(A)

(B)

Figure 5. Low-altitude aerial views of Sparkplug Canyon debris flow. (A) Looking directly up axis of flow; (B) Off-center view showing narrow lobe of debris on southern margin of flow.

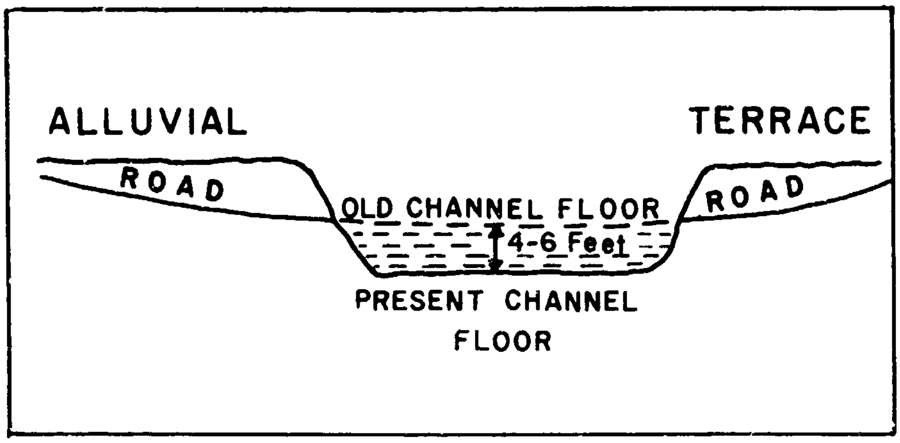
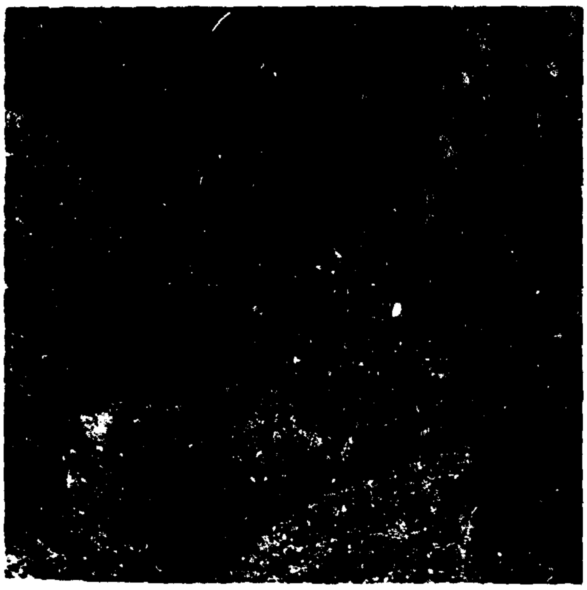


Figure 6. Cross-sectional sketch of site in lower Sparkplug Canyon at which 4 to 6 feet of debris were scoured from channel floor during 1958 debris flow.

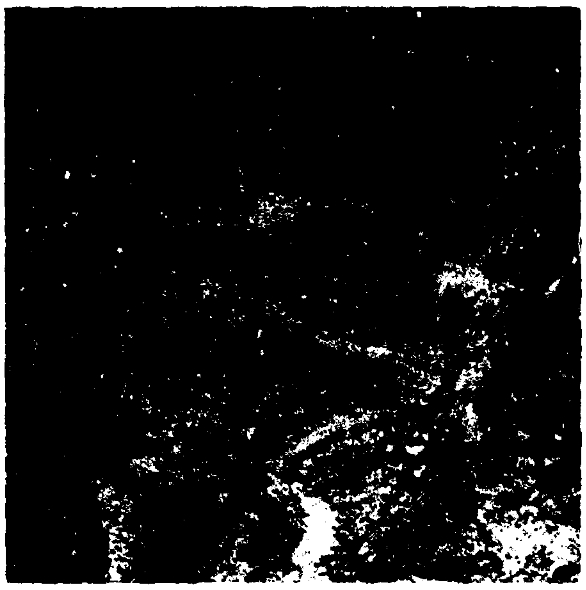
a depth of 1 to 2 feet. But I believe most of the debris was removed from the channel floor in the lower mile of the canyon.

One very interesting piece of evidence indicating the intensity of this debris flow is the moving of a large quartzite boulder from a position well within the lower canyon to the place on the alluvial fan at which spilling of debris from the active channel began, a distance of more than 1 mile. I photographed the boulder, which measures about 12 x 8 x 8 feet, in 1957 at its location on the channel floor of the lower canyon (Figure 7A). Figure 7B is a picture I made of the same site in September 1966. Figure 8 shows the boulder on the floor of the active channel on the alluvial fan. There is no doubt that the boulders shown in Figures 7A and 8 are the same piece of rock. I put liberal amounts of green paint on parts of the boulder in 1957, and although there was a certain amount of abrading and rounding of sharp projections and edges while it was being transported in the debris flow, recognizable remnants of that paint were still present in 1966.

Below the point on the fan at which temporary damming is assumed to have taken place (point "A", Figure 3), the debris flow stayed within the active channel for about half a mile. At places in this reach the mobile rubble was 12 to 18 feet deep, as indicated by the height above the channel floor of remnants of fresh material. At one place where the channel makes a tight bend to the north (point "B", Figure 3), fluid debris spilled over the south bank at the head of the bend and over the north bank at its lower end. The height of debris remnants on the walls of the channel makes it apparent that the surface of the



(A)



(B)

Figure 7. (A) Boulder on floor of lower Sparkplug Canyon; picture taken September 1956. (B) Same view, picture taken September 1966; note that boulder is missing.

Figure 8. Boulder moved from site in lower canyon (see Figure 7A) to alluvial fan by 1958 debris flow in Sparkplug Canyon.

rubble flow underwent tilting, or pendulation, in this stretch of channel, sloping toward the north at the beginning of the bend and toward the south in the downfan segment. Where these minor spillouts occurred, the depth of debris must have been 20 to 25 feet, although its average depth in this sector of channel was much less, perhaps only 10 to 12 feet.

It is not clear why spilling out from the active channel and the beginning of lateral spreading of the debris took place at the particular locality on the fan that they did. The active channel is cut to a depth of 10 to 15 feet at this site, whereas it shallows considerably only a few hundred yards down the fan. It is possible, perhaps probable, that a temporary debris dam formed at this place, thereby forcing the oncoming material to overflow the banks of the active channel and begin its lateral spreading. Assuming that this actually happened, one can also speculate that the blockage in the active channel was eventually removed by high-water flooding. In any case, the debris flow of 1958 spilled out of the active channel and began its lateral spread at almost exactly the same place that an earlier rubble flow had. No particular significance is attached to this fact. Formation of temporary debris dams and plugging of active channels by large boulders have frequently occurred on many of the White Mountains alluvial fans. Frequent course changes caused by

damming and plugging of this sort are responsible in large part for creating the radial systems of abandoned channels so characteristic of the surfaces of White Mountains fans.

(5) Summary

Although the morphologic effects of the Sparkplug Canyon debris flow are apparent, there is still a certain amount of doubt about its origin. In almost every respect the deposit resembles that produced by the typical summertime cloudburst. Yet the one witness with whom I was able to talk asserted positively that the debris flow resulted from excessive snowmelt runoff. A review of pertinent data from the weather station closest to the scene indicates that meteorological conditions during the presumed time of occurrence were favorable for significant snowmelt; a heavier-than-normal snowpack existed along the crest of the White Mountains and higher-than-normal temperatures were experienced in the area during May 1958. I therefore conclude that this debris flow was generated by snowmelt runoff, although the circumstances were somewhat unusual. I believe, however, that debris flows of this magnitude during the period of most active melting of the mountain snowpack must be considered to be extremely rare in the region of interest to this study.

b. Willow Creek, Summer of 1958 [?]*

I could learn very little directly about a small debris flow that issued from the north fork of Willow Creek sometime during the decade 1957-66. Even the indicated date [1958] is in question. A ranch at the periphery of the Willow Creek alluvial fan has undergone two changes of ownership in the past 10 years, and the present operators were unaware of the existence of the debris flow on the fan. In a chance encounter, one of the earlier owners gave a "guess" as to the year of occurrence; this former resident thought it likely the flow occurred in 1958, probably some time in August (Symons, W., personal communication, 1967). A check of precipitation records for the Mount Barcroft weather station (located about 8-1/2 airline miles southeast of the Willow Creek catchment basin) showed that August 1958 was exceptionally wet, with a total of 4.17 inches of rain (Pace, 1963). In the absence of more precise information, I assume that the Willow Creek flood and debris flow occurred in August 1958.

The Willow Creek debris flow spread fresh material on the alluvial fan in the form of an elongated depositional strip flanking one of its many channels (Figure 9). This debris flow is somewhat unusual because of its comparative narrowness; other recent flows on White Mountains fans have tended to be considerably wider, both relatively and in the absolute sense. The channel down which the Willow Creek flow moved is

* Brackets indicate that this date is uncertain.

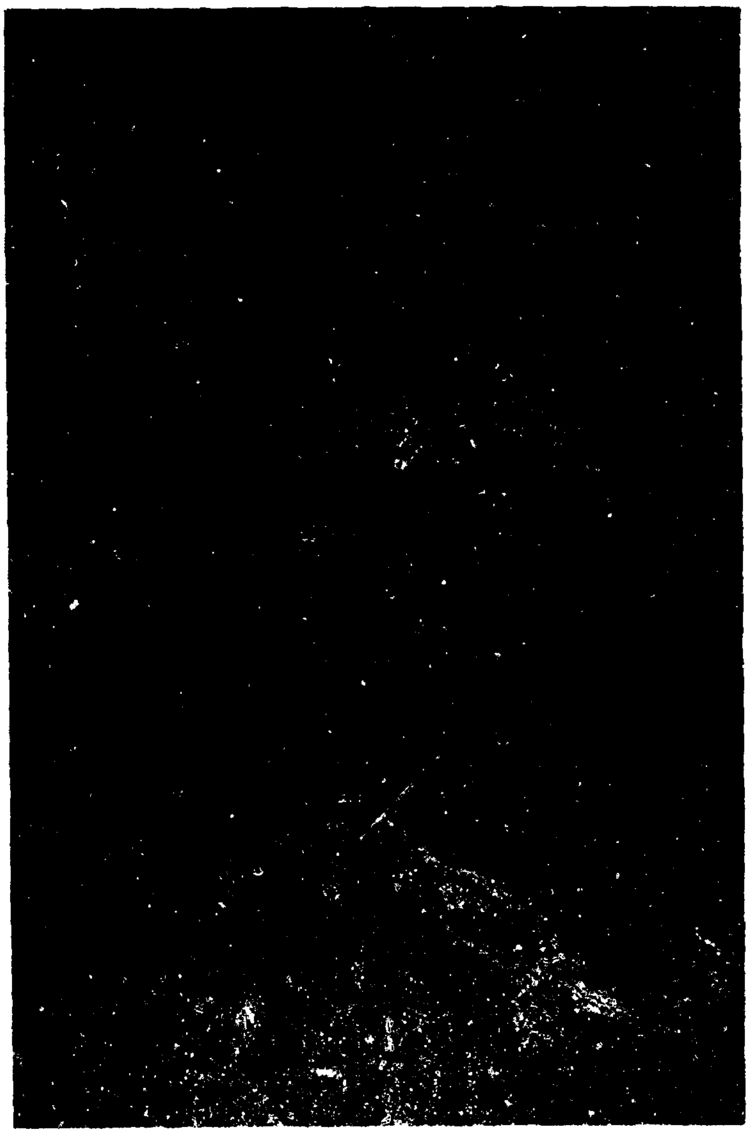


Figure 9. Aerial view of narrow debris flow on Willow Creek alluvial fan, assumed to have occurred in 1958.

cut to a depth of 10 to 12 feet at the fan apex; it shallows to an average depth of 1 to 3 feet where the flow splits into several lobes. In these respects it differs very little from similar channels on nearby fans.

Careful inspection of aerial photographs of the Willow Creek alluvial fan indicates that it has been constructed by repeated debris-flow deposition and that most of the recognizable older flows on its surface were much wider than the most recent one. The material in the 1958 [?] flow is typical fanglomerate (Lawson, 1913); that is, it consists of a heterogeneous mixture of angular debris, ranging from 8-foot granite boulders to fist-sized cobbles, pebbles, and fine sand. In terms of composition, the 1958 [?] flow appears to be almost identical with other recently deposited masses of debris on alluvial fans in the White Mountains area. The relative narrowness of this flow apparently cannot be ascribed to special or unusual geomorphic or lithologic characteristics of the surface over which it moved or the material of which it consists.

A possible explanation, and one that I favor, would involve a consideration of the water content, and therefore the fluidity, of the mobile debris. One of the few modern debris or mud flows in which water content has been accurately determined occurred near Wrightwood, California, in 1941. Measurements of water content in the Wrightwood flow ranged from 20 to 30 percent by weight (Sharp and Nobles. 1953, p. 552-553); that flow attained an extreme length of 15 miles in a descent of nearly a vertical mile. The 1958 [?] Willow Creek flow was on a much more modest scale, extending only about 2-1/2 miles from the canyon mouth to the lower part of the fan. I postulate that its fluidity was greater - and therefore its water content higher - than that of other recent White Mountains debris flows and that it therefore had greater mobility and was less likely to spill out of the channel and spread laterally. Since <u>no</u> measurements of water content in White Mountains flows have been made, percentages of water content are unavailable and must be expressed only in comparative terms.

A reconnaissance on foot up the lower 1-1/2 miles of the canyon of Willow Creek's north fork revealed that most of the fresh debris on the fan came from the floor of the trunk canyon. In places it appeared that as much as 6 to 8 feet of unconsolidated alluvium and colluvium had been removed. The source area for this flow seems to have been the same as that for recent flows on adjacent fans, i.e., much of the rubble came from the trunk canyon floor, rather than from tributary drainages or the walls of the trunk canyon itself. In this respect the 1958 [?] Willow Creek debris flow closely resembles the much more massive flows of 1952 in the drainage systems of nearby Cottonwood Canyon, Lone Tree Creek, and Milner Creek (see Kesseli and Beaty, 1959, p. 42-44).

In summary, the morphologic evidence strongly suggests that the Willow Creek debris flow of 1958 [?] was a typical White Mountains summertime phenomenon, generated by heavy rain in the upper catchment

basin, deriving most of its volume of solids from the floor of the trunk canyon, and following a pre-existent channel for much of its length on the subjacent alluvial fan. I believe that its comparative narrowness was the result of a large water content, by which it acquired greater flu[illegible]y than that possessed by other recent flows in the study area, although I lack direct or even unequivocal indirect evidence that this was so.

c. Montgomery Creek, 30 July 1965

A major debris flow developed in the lower canyon and on the upper part of the alluvial fan of Montgomery Creek on the night of 30 July 1965 (Figure 10). The Montgomery Creek drainage is at the northern end of the western flank of the White Mountains, heading under Montgomery Peak (elevation 13,441 feet) and the north end of Pellisier Flats (elevation 13,484 feet). The mouth of the canyon is about 3 airline miles east and slightly north of Benton Station, California, at an elevation of approximately 6,800 feet. Although the lower mile is comparatively gentle, the trunk canyon of Montgomery Creek has an average gradient of nearly 1,200 feet per mile and is considered to be of the "Falls Canyon" type; that is, it is steep over the greater part of its length.

Since it occurred at night, there were no eyewitnesses to this debris flow. However, most of the residents of Benton Station heard loud rumbling and roaring noises seemingly emanating from the vicinity of Montgomery Creek and assumed that a serious flood was in progress. The California Division of Highways closed Federal Highway U.S. 6 to southbound traffic at Benton Station for about 6 hours on the night of 30-31 July 1965, although as it turned out, no water or debris from Montgomery Creek reached the roadway. In view of the flooding history of the western side of the White Mountains, closing the highway was certainly justified as a safety measure, particularly since the Montgomery Creek flood took place at night. The fact that its effects did not extend to the margin of the fan, along which U.S. 6 is located, is remarkable and will be commented on later in this section.

(i) Precipitation

The month of July 1965 appears to have been wet and stormy throughout the White Mountains area. Weather maps for the period indicate that strong southwesterly flow aloft brought a more or less continuous supply of moist, potentially unstable air into the region from the Pacific Ocean. Isolated thunderstorms were widely reported, and minor flooding of "dips" and other low spots on highways seems to have been common.

On the day of the debris flow, 30 July, rain was general in and near the northern White Mountains. Two weather stations provide information on possible precipitation intensity and duration in the vicinity of Montgomery Creek: (1) a California Department of Agriculture inspection

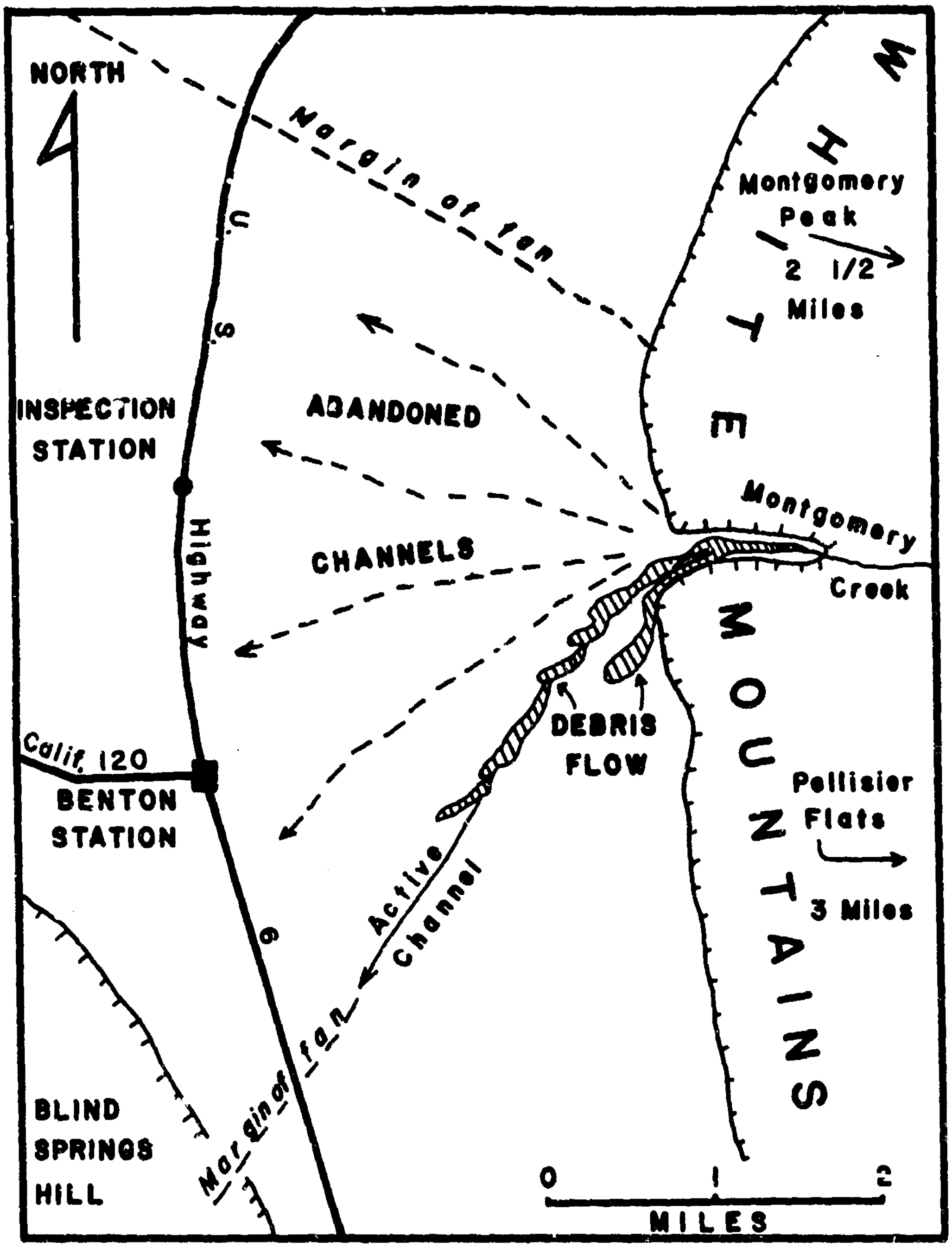


Figure 10. Sketch map of Montgomery Creek alluvial fan showing debris flow of 30 July 1965 and location of Benton Station and California Department of Agriculture Inspection Station. Base: U.S.G.S. 15-minute Benton topographic quadrangle.

Station on U.S. Highway 6 about 1-1/2 miles north of Benton Station; (2) a Nevada state highway maintenance station at Montgomery Pass. The Inspection Station is located 3 miles west of the mouth of Montgomery Creek canyon at an elevation of 5,460 feet. Rain during the afternoon and early evening at the Inspection Station amounted to .39 inch. The maintenance station at Montgomery Pass (elevation 7,150 feet) is about 11-1/2 airline miles northeast of Montgomery Creek; here, .85 inch of rain fell on 30 July between 2:00 p.m. and 9:00 p.m. At neither station was local flooding reported on this date.

Precipitation in the Montgomery Creek catchment basin must have been much more intense, but the total is unknown. Local residents stated that heavy rain fell intermittently in the vicinity of Montgomery Peak throughout the afternoon and into the early evening of 30 July. They also noted that the mountains were obscured by clouds and/or precipitation most of this time and that lightning and thunder were frequent. It seems probable that at least 1-1/2 to 2 inches of rain fell in Montgomery Creek, and the total amount may have been much greater. The figures are suggested because in the past in the White Mountains it has taken this much precipitation as a minimum to produce significant movement of large masses of debris.

(2) Accounts of Local Residents

As mentioned above, there were no eyewitnesses to the Montgomery Creek debris flow. However, most of the citizens of Benton Station were in the community on the evening of 30 July because a farewell party was being held for a long-time resident who was moving away. Many of the people were assembled at a state highway maintenance station, and it was evidently this group that first became aware of the rumbling and roaring noises from Montgomery Creek canyon. Personnel on duty at the Inspection Station north of Benton Station also heard loud roaring noises to the east, although they were apparently less certain about the possible place of origin (Patterson, J., personal communication, 1967). The noises seem to have been detected first about 10:00 p.m. (Mathieu, D., personal communication, 1967).

Older residents of the area immediately recognized the sound for what it was, namely, a major debris flow, and some concern was expressed for the safety of Benton Station. As the roaring noise continued and seemed to grow louder, a number of people moved their families by car to the Inspection Station north of the community. In the meantime, southbound traffic on U.S. 6 was being halted at a roadblock in Benton Station.

Accounts differ as to how long the rumbling and roaring noises were heard, but it seems probable that they lasted about 1-1/2 to 2 hours (Mathieu, J., personal communication, 1967). Highway maintenance personnel patrolled U.S. 6 south of Benton Station for most of the night,

expecting at any minute to be confronted with at least high water across the roadway, but no evidence of serious flooding was seen. As the noises to the east subsided and no indications of major flooding appeared, residents of the community assumed the worst was over and retired for the night.

On the morning of 31 July, light-colored fresh debris could be seen on the south side of the apex of the Montgomery Creek alluvial fan from U.S. Highway 6 south of Benton Station. A few people drove to the mouth of the canyon to investigate results of the debris flow. It was reported that no evidence of debris movement could then be detected and that Montgomery Creek, although somewhat muddy, was not experiencing excessively high discharge (Mathieu, J.). However, the stream channel in the lower canyon and on the uppermost part of the alluvial fan had been deepened and widened almost beyond recognition. In addition, a sizable volume of fresh rubble had been dumped on the upper part of the fan surface. Since water from the Montgomery Creek drainage system is used only to irrigate a small acreage of natural pasture, most of the residents of the area gave the debris flow but passing attention; it had not interfered directly with their lives or livelihood and therefore represented no more than a momentary distraction, frightening at the time but soon forgotten.

(3) Morphologic Effects

Without a doubt the most spectacular morphologic effect of the Montgomery Creek flood and debris flow was the cutting of an enormously enlarged active channel in the lower canyon and in the transitional zone where the canyon mouth-fan apex juncture is found. Compared with the formation of this remarkable geomorphologic feature, deposition of a large mass of fresh debris on the alluvial fan seems almost a secondary event, undeniably significant but not so very different from other recent debris flows on White Mountains fans.

The lower mile of Montgomery Creek canyon differs somewhat from other west-side White Mountains drainages in that the canyon floor widens from only a few feet at its upper end to about 500 feet at the mouth (Figure 11A and 11B). Alluvium to a maximum depth of several hundred feet covers most of the canyon floor. The present active channel is closer to the south canyon wall than to the north and is cut into the alluvial fill over all of its length. Along the northern edge of the alluvium-floored lower canyon there is an abandoned channel as much as 30 feet deep that was probably cut by a flood in the middle 1940's.

Within the lower canyon the flood and debris flow of 30 July produced striking morphologic results. The most conspicuous were (1) a widening and deepening of the active channel and (2) deposition of fresh debris. Figures 12 through 15 present a series of "before" and "after" photographs taken in 1956 and 1966 respectively at various places in the lower canyon. The pictures clearly show that the detailed morphology of the lower canyon

(A)

(B)

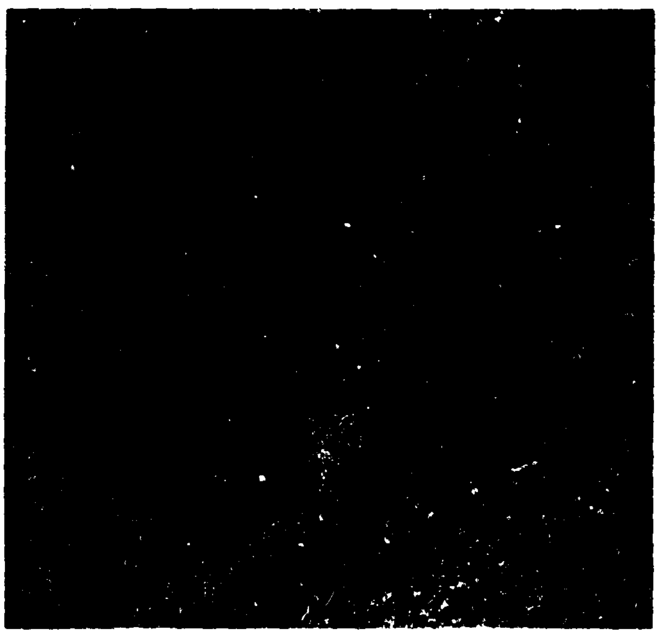
Figure 11. Views upstream (A) and downstream (B) in lower canyon of Montgomery Creek, taken in 1966 from location on north canyon wall. Widening of lower canyon is evident.

(A)

(B)

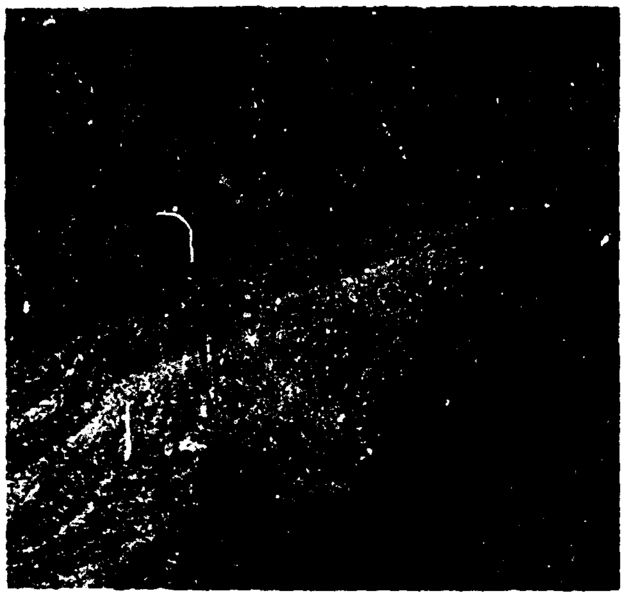
Figure 12. Views of bedrock waterfall at head of lower canyon of Montgomery Creek, taken in 1956 (A) and 1966 (B). Large boulder (arrow) immediately above falls in (A) is absent in (B), as is the boulder (arrow) on channel floor in the immediate foreground of (A).

(A)

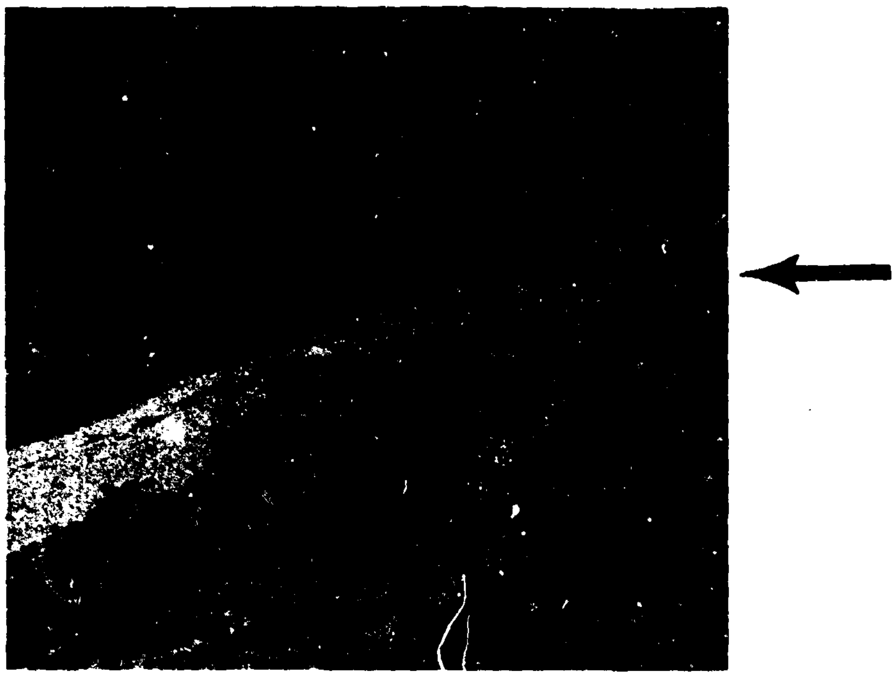


(B)

Figure 13. Looking downstream in Montgomery Creek Canyon from about 1 mile above its mouth. (A) The scene in 1956; (B) as it appeared in 1966. Widening and deepening of the active channel by the 1965 flood and debris flow are apparent.

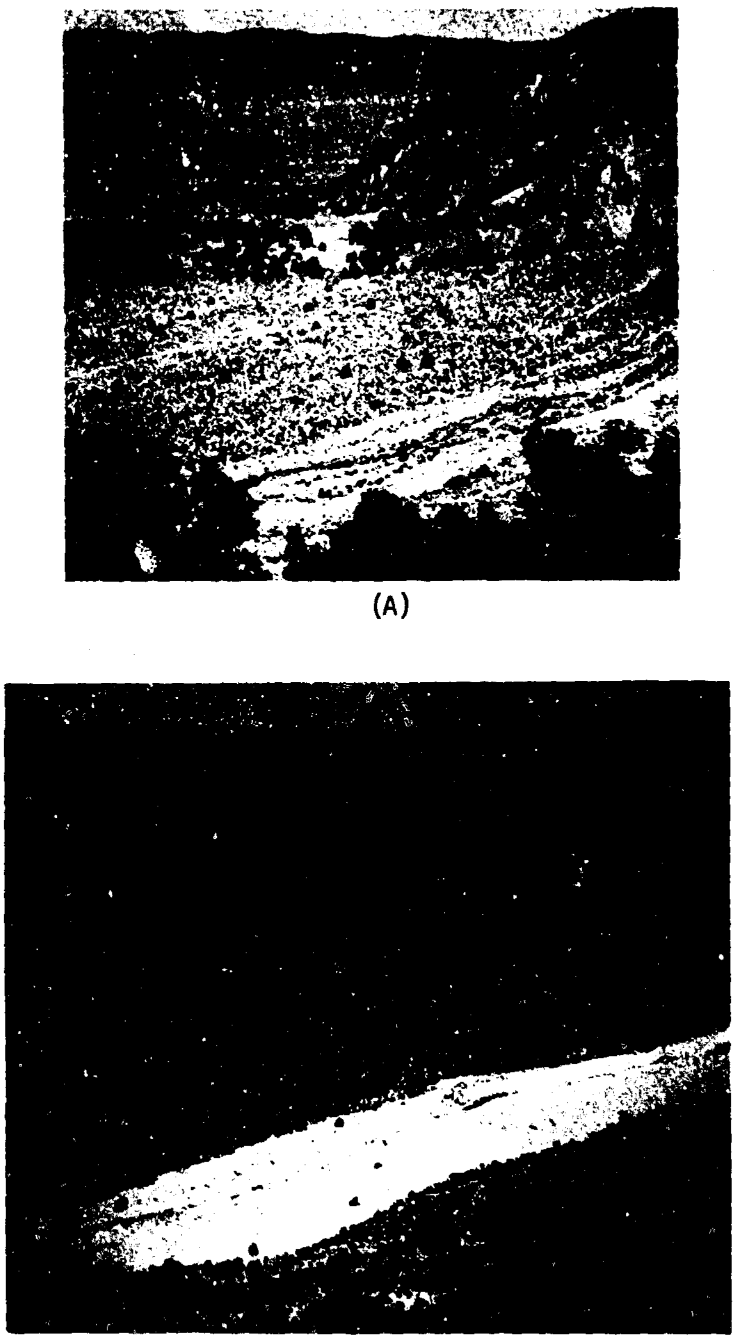


(A)



(B)

Figure 14. View of floor of Montgomery Creek Canyon about 1/4 mile above the canyon mouth. (A) As it appeared in 1956; (B) same view in 1966. Both channel deepening and debris deposition occurred in this part of the canyon. At a point (arrow) near center of right-hand margin of (B), temporary damming of the debris flow caused spreading to take place and a subsidiary lobe of rubble to branch from the main mass.



(A)

(B)

Figure 15. Looking north across the mouth of Montgomery Creek Canyon. (A) Picture taken in 1956. (B) Picture taken in 1966; fresh material from the 1965 debris flow mantles both sides of the active channel, which was deepened significantly at this point.

was significantly altered. As will be discussed later in this section, I believe that a great mass of fluid debris first rushed down the lower canyon, soon to be followed by primarily high-water flooding in Montgomery Creek. The debris flow proper stayed in or close to the pre-existent active channel over much of its course through the lower canyon. At one point, however, temporary damming occurred (Figure 14B); here, the debris flow spread to cover most of the width of the canyon floor, and a subsidiary lobe branched off to the left, or south, following the base of the south canyon wall to and beyond the fan apex.

The amount the active channel was enlarged varied considerably within the lower canyon, but on the average it would appear that the channel was deepened 4 to 8 feet and widened by as much as 6 to 10 feet. Average thickness of the freshly deposited debris is 2 to 4 feet, although there is considerable variation in this parameter as well.

Figure 16 is a low-altitude oblique aerial photograph of the lower canyon and part of the upper fan surface of Montgomery Creek. The debris flow dammed and spread at a point near the bottom of the picture; the subsidiary debris lobe and channel along the base of the south canyon wall are clearly visible. Downcanyon from the area of widest spreading, about a third of the way from the top of the photo, there is a zone of secondary spreading. Figure 17 gives a closer view of this zone; the picture was taken from low on the south canyon wall. An unusual series of boulder ridges is located on the surface of this part of the debris flow, the origin of which is not fully understood (Figures 17 and 18). Segregation of larger boulders along the margins of debris flows on alluvial fan surfaces into debris flow lateral ridges (Kesseli and Beaty, 1959, p. 49) or mudflow levees (Sharp, 1942) has been reported; presumably the linear accumulations of boulders in this and other parts of the Montgomery Creek flow are analogous.

The active channel of Montgomery Creek underwent greatest enlargement in the zone of transition at the canyon mouth - fan apex juncture. Here, where in 1957 the creek occupied a channel only 2 to 4 feet deep, it is now flowing at the bottom of a cut that attains an extreme depth of nearly 40 feet (Figure 19 A and B). Not only has the channel been significantly deepened, it has also undergone considerable widening in this sector, from an estimated 10 to 12 feet in 1957 to a width of 30 to 40 feet at present. An aerial view of this segment of the channel (Figure 20) gives a different perspective, in which both the width and depth of the enlarged channel can be seen.

The primary effect of the debris flow on the alluvial fan was deposition of fresh rubble (Figures 21 and 22). The active channel on the apex immediately below its zone of extreme enlargement also seems to have been deepened and widened, although I could not determine exactly to what extent. Debris reached the fan surface in two lobes (see Figure 22B). The larger mass of rubble moved in and close to the active channel. A smaller volume of debris was deposited just outside the

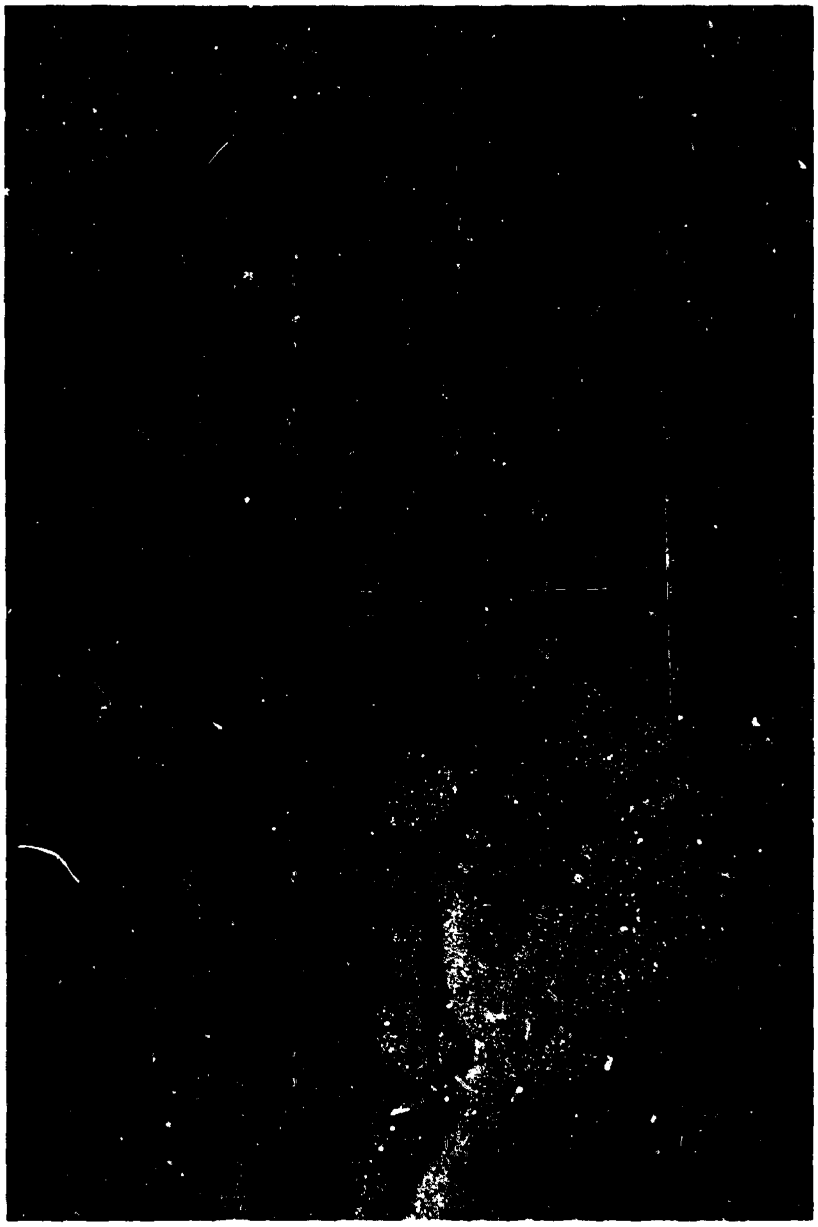


Figure 16. Aerial view looking downstream from about 800 feet above the floor of lower Montgomery Creek canyon. Zone of secondary spreading indicated by arrow.

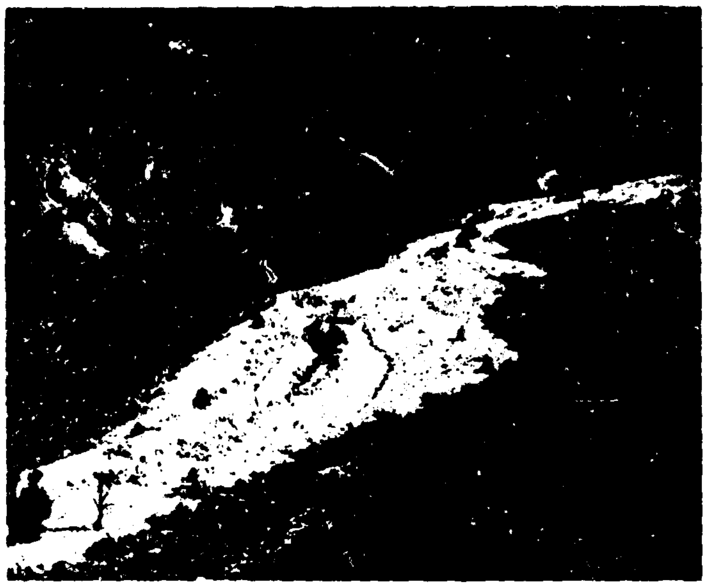
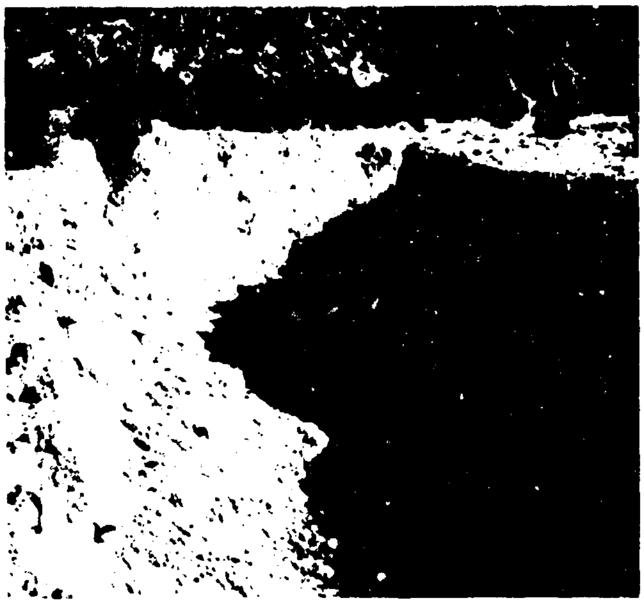


Figure 17. Area of secondary debris spreading just above mouth of Montgomery Canyon. Linear accumulations of large boulders can be seen on both sides of the active channel.

Figure 18. Boulder ridges in lower Montgomery Creek. From the edge of the incised channel to the left margin of the flow at least three distinct ridges can be seen.



(A)

(B)

Figure 19. Views of the greatly enlarged active channel of Montgomery Creek from (A) the south rim of the channel and (B) its floor. The pinyon pine trees on the north side of the channel in (B) are about 15 feet high.

Figure 20. Low-altitude aerial view of the active channel of Montgomery Creek at the canyon mouth-fan apex juncture; debris spilled out of active channel at the point of its closest approach to the south canyon wall (arrow), there to join the subsidiary lobe coming downcanyon from the point of diversion about 1/2 mile above the mouth (see Figure 16).

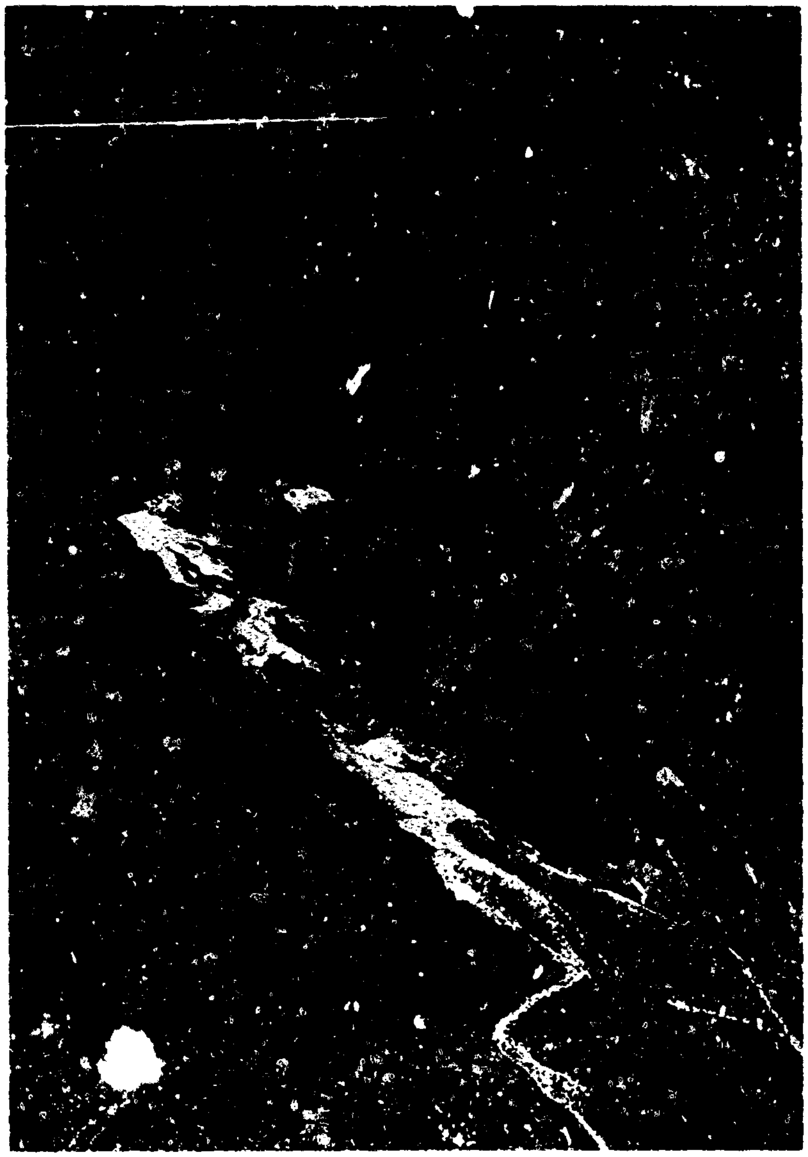
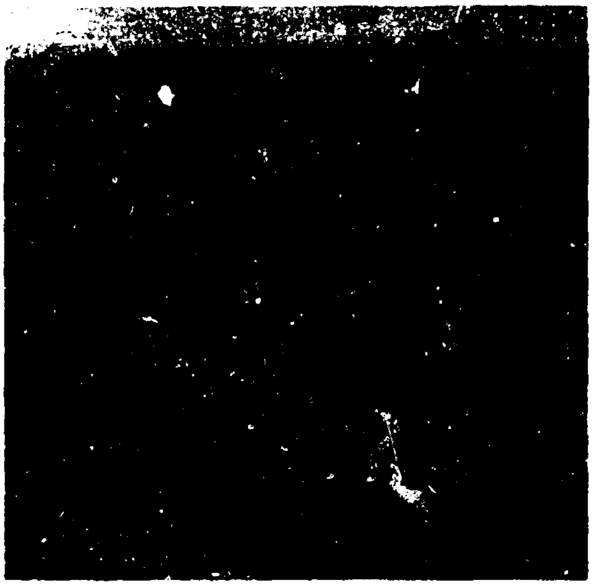


Figure 21. Aerial view of debris flow on south side of upper part of Montgomery Creek alluvial fan. Irregular distribution of patches of debris on fan surface is apparent.



(A)

(B)

Figure 22. "Before" and "after" photographs ᶠ part of the Montgomery Creek fan, taken from a point just above the south side of the canyon mouth. (A) The view in 1956; (B) as it appeared in 1966. Blind Springs Hill lies immediately beyond the floor of Upper Owens Valley at the fan margin; the Sierra Nevada is on the skyline.

canyon mouth along the southern margin of the apex (Figure 23). Most of

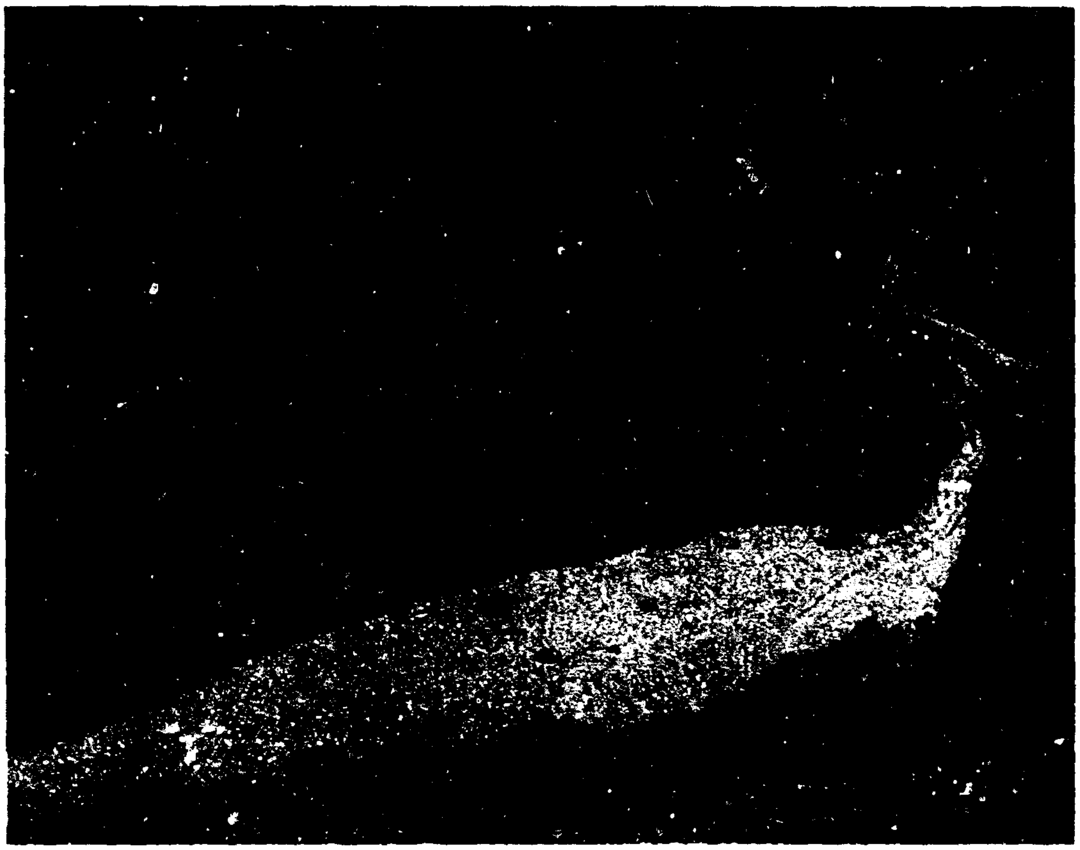


Figure 23. Aerial view of subsidiary debris lobe on south side of apex of Montgomery Creek fan. The same lobe is particularly conspicuous on the left side of Figure 22B.

this latter material represents debris moved in the subsidiary lobe that branched from the active channel within the lower canyon (see Figure 16); some of it, however, must have come from a spillout on the south side of the active channel near the zone of its deepest entrenchment. This latter spillout can be seen near the center of the photograph of Figure 20.

The general course of the debris flow on the Montgomery Creek alluvial fan was in or close to the intertan depression at the southern margin, along which the active channel has been situated since at least the early 1940's. In this case - as has been true of other recent debris flows in the White Mountains area - the location of the active channel on the fan

controlled the course of the moving rubble.

The material moved by the Montgomery Creek debris flow was largely granitic and ranged in size from 12-foot boulders to coarse and medium sand. On the fan the thickness of freshly deposited debris varies from 8 to 10 feet in a few places near the apex to less than 1 foot near the lower margin of the flow. The highly irregular distribution of patches of debris on the fan surface - clearly visible in Figures 21 and 22 - seems to have been brought about by temporary damming of the active channel down which much of the fluid rubble was moving. Plugging of the channel apparently caused the debris to spread laterally for a time, after which flow continued in or marginal to the channel, only to be dammed again farther down the fan. As in other recent White Mountains flows, there is no apparent morphologic reason why initial spilling out of the moving debris occurred where it did on the fan. One can only assume that the active channel was plugged at this point and that the large boulder or accumulation of boulders responsible for temporary damming was subsequently removed and transported farther down the surface.

As mentioned above, I believe that the Montgomery Creek debris flow came <u>before</u> significant high-water flooding occurred. This general pattern of events has been fairly common in western America: quite typically, excessive discharge of muddy water will continue 24 to 48 hours after a major debris flow has taken place. However, <u>prolonged</u> high-water flow did not occur in Montgomery Creek on 30-31 July 1965. Residents of Benton Station who examined the debris flow at the mouth of the canyon on the morning of 31 July, less than 10 hours after the event, reported that the creek, although muddy, was no higher than usual. It should also be stressed that flood runoff from Montgomery Creek failed to reach U.S. Highway 6 on the margin of the alluvial fan. In the past, comparable floods and debris flows along the west side of the White Mountains have almost always put at least high water across the valley floor highway, and in many cases large volumes of fairly coarse debris have been transported all the way to fan peripheries.

A possible clue to the seemingly anomalous behavior of Montgomery Creek is provided by testimony of one of the residents of Benton Station. This man, who works at the inspection Station north of the community, stated that a landslide had occurred high on the south wall of middle Montgomery Creek canyon, probably on the same night the debris flow took place (Reichert, F., personal communication, 1967). The presumed source area was pointed out, and I visited the slope in question in an attempt to verify the occurrence of a slide. Positive verification was impossible; the slope on which the slide was reported to have moved is extremely steep and largely veneered with what appears to be fresh and active talus. In several places even the weight of a man was enough to start large blocks moving, and it seems probable that some of the talus moves every year. In any event, I did not find a conspicuous,

unmistakable landslide scar. Also, investigation of the floor of the canyon at the foot of a chute down which the slide would have come produced inconclusive results. I found no unequivocal evidence that a temporary landslide dam had existed on the canyon floor. A large number of massive, unweathered granite boulders is resting on the canyon floor at this site, but such blocks are common along much of the channel in this part of the canyon. However, more than 2 years have passed since the debris flow, and it is not unreasonable to suppose that much of the evidence of landslide damming of Montgomery Creek has since been destroyed or modified beyond ready recognition.

If a major landslide did occur, and I believe this likely, it is possible to imagine the following sequence of events in the Montgomery Creek drainage system:

1. The slide temporarily dammed the creek in the middle canyon.
2. As precipitation and ponding of surface runoff continued, the slide debris became saturated.
3. The saturated rubble lost its stability and moved down the canyon as a typical debris flow, its course largely guided by the location of the active channel in the lower canyon and on the fan. Most of the fresh material in the lower canyon and on the upper part of the fan was deposited at this time.
4. Particularly intense precipitation in the upper catchment basin then produced a spasm of high-water flooding, the most important effects of which were to deepen the channel and transport the debris thereby removed to the middle part of the southern margin of the alluvial fan.

In this postulated reconstruction, much or most of the channel enlargement in the lower canyon and on the fan apex is attributed to the brief but morphologically potent episode of high-water flooding. There is strong evidence that high-water flow did indeed follow debris deposition. At a number of places in the lower canyon a thin layer of fine debris overlies coarser debris immediately adjacent to the edge of the active channel (Figure 24). The spatial relationship of the finer to the coarser material indicates that the finer debris must have been deposited after the blockier rubble. The relative fineness of and lack of larger boulders in the finer material suggests that it was deposited by water heavily charged with sand and pebbles, but on the whole lacking cobbles and larger blocks. It is the high-water flow responsible for deposition of this finer debris that is believed to have accomplished the spectacular deepening and widening of the active channel.

Critical to this postulated reconstruction of events is the assumption that brief but torrential rain followed destruction of the landslide dam in the middle canyon, an assumption that cannot be directly sustained. However, the fact that heavy runoff from Montgomery Creek did not reach the margin of its alluvial fan suggests that only a limited amount of water was available during the flooding incident. It seems necessary in

Figure 24. Thin layer of finer material overlying coarser debris at edge of channel; picture taken about 1/4 mile inside lower Montgomery Creek canyon.

this case to suppose that precipitation distribution, in both time and place, was "just right" to produce the observed effects. Testimony of local residents is of no help in this matter; they were aware of the noises made by the debris flow but had no ideas about rain in the mountains during and following the flow.

(4) Summary

In terms of destructive potential and geomorphological effects, the Montgomery Creek debris flow and flood of 30 July 1965 was easily the most outstanding event of the 1957-66 decade in the White Mountains. Had it occurred during the daylight hours, a number of people would probably have been able to make first-hand observations. In particular, it

would be useful to know with more precision the order in which high-water flooding and debris flowing took place. Better information about precipitation intensity and duration within the affected catchment basin would also be of value; "guesses" about precipitation remain a necessity in this and most other instances of desert flooding.

In spite of certain deficiencies in the record, I feel that the account of this major episode of flooding here presented is valid and that at least the general course of events has been correctly reconstructed. Admittedly, specific details are lacking, but these could have been provided only by personal observation of the debris flow and flood in action.

d. Other Floods During the Decade

A number of smaller, less conspicuous floods occurred in and around the margins of the White Mountains during the decade 1957-66. Most seem to have had little influence on human activity and were therefore undetected or ignored by local residents. In southern Fish Lake Valley, for example, three or four small debris flows developed in minor drainages south of McAfee Creek some time during this period, but I couldn't find residents of the valley who knew when they might have happened. Similarly, during investigations in the larger canyons I discovered several small range-front rubble flows along the northwestern flank of the mountains. These flows were not present in 1957, but I don't know when they might have taken place. Most smaller floods and debris flows, unless they directly affect roads or ranches in the area, seem to go unnoticed by most residents of the region.

On the other hand, snowmelt flooding in several large White Mountains drainages has been almost a yearly occurrence and a more or less constant source of trouble for ranchers and highway maintenance personnel on both sides of the range. The stream systems in question - Cottonwood Canyon, Lone Tree Creek, and Milner Creek on the west, and Leidy Creek on the east - are those that had major floods and debris flows in July 1952 (see discussion in Kesseli and Beaty, 1959, p. 34-55). In all of these drainages the most significant effect of the 1952 floods was removal of unconsolidated alluvium and colluvium from trunk canyon floors, leaving the trunk canyons essentially bedrock chutes over much or all of their lengths. The results, so far as runoff characteristics are concerned, have been of immediate practical consequence, since all of the streams are used for irrigation and two of them for hydro-electric power generation. Additionally, higher-than-normal runoff from these drainage systems finds its way to and across major highways in Upper Owens Valley and Fish Lake Valley, interfering, at times seriously, with the normal flow of traffic.

The problem in these stream systems, although varying in intensity from year to year, has been basically the same since 1952. Briefly, lack

of an effective "sponge" of alluvium and colluvium on trunk canyon floors has meant that snowmelt runoff tends to fluctuate widely during the day-night-day cycle. Instead of being soaked up slowly and released gradually over a period of several days, each afternoon's snowmelt rushes down the trunk canyons and onto adjacent alluvial fans in a matter of only 10 to 12 hours. Maximum and minimum discharges in these drainages vary in volume by as much as a factor of 20 or 30, and there are many difficulties created by such violent fluctuations of runoff in the lower canyons. I observed the effects of high snowmelt runoff in Milner Creek in May and June 1957 (Kesseli and Beaty, 1959, p. 60-66). It is of interest to note that almost identical effects were observed during May and June 1967; these are discussed in a later section of this report.

The major damage associated with excessively high and fluctuating snowmelt runoff has been the destruction or plugging with debris of pipeline intakes on lower trunk canyon floors, as a result of which ranches have been deprived of irrigation water at a crucial time. Heavy runoff has also created problems for highway maintenance personnel, since stream flow that normally would be used productively has washed across roads, slowing and at times stopping vehicular traffic.

In summary, the most significant small-scale flooding during the decade 1957-66 in the White Mountains has been that associated with snowmelt runoff in selected drainage systems. Although damage in terms of dollar values has not been very great in a single year, the cumulative effect over the decade is considerable. Aggravating the situation is the fact that man can do little to alleviate conditions in the flood-producing canyons. Natural replacement of the "sponges" of alluvium and colluvium is proceeding slowly, at best, and it will be many years - probably centuries - before the affected drainages will cease yielding potentially destructive snowmelt floods.

3. Floods During Period of Field Study (Sept 1966 - Aug 1967)

During the current period of field investigation, flooding in and near the White Mountains was of all three types mentioned earlier in this report: Wintertime Flooding occurred in December 1966; Snowmelt Flooding was observed in May and June 1967; and Cloudburst Flooding took place in July and August 1967. Although no massive, spectacular floods and debris flows developed in the immediate White Mountains area, runoff was relatively high on several occasions, and a number of potentially useful first-hand observations were made.

a. Heavy Precipitation and Flooding, 2 through 7 December 1966

Almost unprecedented amounts of rain fell in Owens Valley and on lower White Mountains and Sierra Nevada slopes during the first week of December 1966. Snowfall at higher elevations was also heavy, equaling or exceeding long-time records in the southern Sierra Nevada and also

probably in the White Mountains. In this period measured rainfall on the floor of Owens Valley was generally greater than 5 inches, and two City of Los Angeles Department of Water and Power weather stations, at Big Pine and Independence, had totals of slightly more than 11 inches. Snowfall along the crest of the White Mountains was more than 90 inches at Mount Barcroft and reached 70 inches at the Crooked Creek station; depths in the Sierra Nevada were considerably greater.

The synoptic situation giving rise to such unusual amounts of precipitation is graphically portrayed on weather maps for the period. Both at the surface and aloft, a large low-pressure center remained essentially stationary off the northwestern Pacific coast from 1 December to 7 December, and strong circulation around its southern margin brought plentiful amounts of moist air across California and into the western Great Basin. Similar circulation patterns must have prevailed at times in the past, but rarely since the beginning of the historical period has so much precipitation fallen in such a relatively short time during the winter months in the White Mountains-Owens Valley-Southern Sierra Nevada region.

Within the White Mountains, flooding with damage to roads and other man-made features was only moderate. South of Bishop, California, on the floor of Owens Valley, considerable damage was done to main and secondary highways, and the Los Angeles Aqueduct (which normally carries the full flow of the lower Owens River) was cut in six places between its intake south of Big Pine, California, and the Haiwee Reservoir, south of the usually dry bed of Owens Lake at the southern end of the valley. As a result of breaks in the aqueduct, the lower Owens River drainage system had storm runoff in it for about 10 days, and a broad, shallow body of water came into existence on the bed of Owens Lake. Local residents said this was the first time since the 1930's that the lake bed had had more than a few isolated ponds on it.

The first estimate of flood damage along the eastern Sierra Nevada front exceeded $1,000,000 (Inyo Register, 5 January 1967), although the amount was later scaled down. What the final official total may have been could not be determined; Inyo County, California, alone estimated an expenditure of more than $200,000 on road repairs, and renovation and reconstruction of parts of the Los Angeles Aqueduct must have been expensive. Whatever the ultimate cost in dollars, damage from the floods, especially in southern Owens Valley, was of considerable economic importance.

(1) Morphologic Effects and Damages - White Mountains

Within and adjacent to the White Mountains, morphologic effects of the heavy precipitation were surprisingly slight. A few drainage systems had high runoff on lower trunk canyon floors, but most of the canyons in the range failed to develop unusually heavy discharge. This somewhat unexpected situation was apparently brought about by the fact that the

bulk of the precipitation falling at elevations above 6,500 feet was in the form of snow rather than rain and therefore did not run off rapidly. Catchment areas below 6,500 feet in most White Mountains drainages are limited, and since the high precipitation amounts were accumulated over a period of 4 or 5 days, in only a few cases was the discharge large enough to do effective gradational work.

I made field observations in all of the drainage basins on the west side of the range during and immediately after the period of heavy precipitation. North of Laws, California, only four stream systems showed evidence of unusually high water: Cottonwood Canyon, Lone Tree Creek, Sparkplug Canyon, and Milner Creek. All of these drainages have undergone significant flooding within the past two decades, and all lack over much or most of their trunk canyon floors the "sponge" of alluvium and colluvium so important in controlling the intensity of snowmelt flooding. As a probable result, there was excessive runoff on lower trunk canyon floors and alluvial fans of all of these drainages, by which the active channels on fans were deepened and some of the finer debris transported toward fan perimeters. Discharge from Lone Tree Creek reached U.S. Highway 6 in Upper Owens Valley, where 1 to 1-1/2 feet of sand, silt, and clay were deposited on the roadway.

In marked contrast, other west-side drainage systems north of Laws showed little evidence of higher-than-normal discharge; this was true even in Montgomery Creek, which sustained a major debris flow in 1965 (see above). Observations during the period 2 through 7 December 1966 indicated that snow rather than rain was falling almost to the lower margin of the range along much of the western front, especially in the northern part. Presumably the fact that solid precipitation accumulated in many of the catchment basins accounts for the lack of high runoff in these areas.

On the eastern flank of the White Mountains and the floor of adjacent Fish Lake Valley, Nevada, morphologic effects of the heavy December precipitation were minimal. Total precipitation during the stormy period was much less in Fish Lake Valley than at comparable elevations in Owens Valley, and most of the precipitation that fell east of the crest of the range came as snow. As a result, only Leidy Creek - which underwent major fooding in 1952 - showed higher-than-normal discharge, and little or no damage to roads or structures was reported.

North of Bishop, on the floor of Upper Owens Valley, significant surface runoff was generated in the discontinuous channel system that leads south toward the Owens River. This channel system collects runoff from the western flank of the White Mountains. Since the 1870's, when use of stream flow from the mountains for irrigation was begun, the channel has been dry perhaps 99 percent of the time. But enough rain fell on the valley floor during the period 2 through 7 December 1966 to create sizable flow, which at one place brought about plugging of a

culvert and temporary flooding and closing of U.S. Highway 6. At another locality a short segment of secondary road was completely cut away by the same runoff (Figure 25). For the first time many decades,

Figure 25. Flood damage to secondary road in Upper Owens Valley, caused by the heavy rains of December 1966.

surface flow from the Upper Owens Valley catchment area joined the Owens River near Laws, California, although for only 2 or 3 days.

Of interest to this study was the behavior of surface runoff on White Mountains alluvial fans during the period of heavy precipitation. On a few of the fans, high runoff from catchment areas within the range deepened active channels and transported fine debris toward fan peripheries. On many of the fans, however, runoff seems to have originated on the fan surfaces themselves as a result of rain. On some there was a tendency for surface flow to move in abandoned distributary channels toward and into interfan depressions, along which the shallow runoff was concentrated. This is in contrast to flooding produced by summertime thunderstorms, in which most or at least much of the flow is restricted to the active channel on a fan, with spreading or divergence usually occurring near the lower margin.

Along the southern part of the west side of the White Mountains, from Silver Canyon to the Westgard Pass road, discharge from all of the drainage systems was much greater during the heavy rains of early December than that observed farther north. It is assumed that this was

so because average elevations here are somewhat lower and therefore more of the precipitation within individual catchment areas reached the ground in the liquid rather than solid state. It is also possible that total precipitation amounts were greater in the southern part of the mountains. Considerable damage was done to roads on trunk canyon floors in this part of the range, and in one drainage - Silver Canyon - it was possible to arrive at a reasonably good estimate of the flood-producing precipitation because three non-recording rain gages were fortuitously placed in advantageous locations.

Runoff in lower Silver Canyon badly cut up the road located on its floor for a distance of nearly 1/2 mile (Figure 26) and almost completely

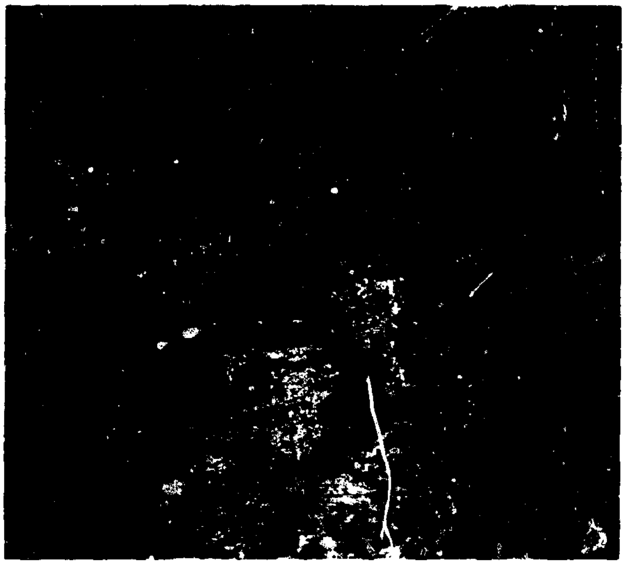


Figure 26. Flood damage to gravel road in lower Silver Canyon.

destroyed it in a few places (Figure 27). On the other hand, higher in the canyon, at elevations above 6,500 feet, the road was essentially intact following the period of heavy precipitation (Figure 28). The remarkable differences in state of preservation of parts of the road are directly attributable to the fact that while heavy rain was falling in lower Silver Canyon, most of the precipitation above 6,500 feet was snow. Surface runoff did develop in the upper canyon, but the total short-time volume was small since it was generated gradually by melting of the snow pack.

The bulk of the water which damaged the road in lower Silver Canyon came from a single, small tributary drainage system that enters the

Figure 27. Section of lower Silver Canyon road almost completely washed away by runoff of December 1966.

Figure 28. Silver Canyon road above zone of major flood runoff, December 1966. Some cutting is evident, but road is passable.

trunk canyon from the north at an elevation of 6,100 feet some 3 miles above its mouth (Figure 29). Precipitation totals at three nearby

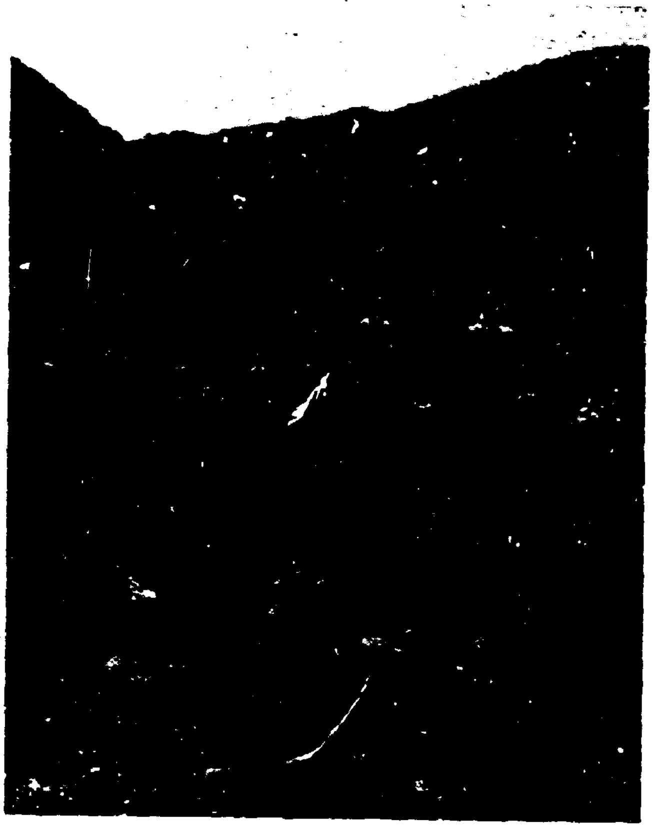


Figure 29. Mouth of Silver Canyon tributary drainage out of which came most of the destructive flood runoff in December 1966. Much of the flow from this tributary canyon simply followed the road down the main canyon.

rain-gages make possible a fairly precise estimate of the total amount of rain in the tributary catchment basin during the period 2 through 7 December 1966. A gage at the mouth of Silver Canyon, 4 airline miles west, caught 5.43 inches of rain. A second gage was located 2 airline miles east of the tributary drainage, higher in Silver Canyon; here, a total of 6.07 inches of water was measured, most of it having fallen as snow. A third gage, at the mouth of Coldwater Canyon about 5-1/2 airline miles northwest, caught 4.81 inches during the indicated period. It seems reasonable to postulate that no less than 5 inches of precipitation, mainly rain, fell in the tributary catchment basin. Much of it probably fell on 5 December, when the largest single daily totals were measured at weather stations on

the floor of Owens Valley and also at the Crooked Creek and Mount Barcroft laboratories on the crest of the White Mountains.

Damage to canyon-floor roads in Poleta and Black canyons, south of Silver Canyon, was comparable to that sustained in the latter. A pair of "before" and "after" photographs in lower Poleta Canyon (Figure 30 A and B) illustrates the changes produced by high water in December 1966; the road was completely destroyed, although it would require relatively little work with a bulldozer to restore it to a usable condition.

The Westgard Pass road, leading east from Big Pine, California, to Deep Springs and southern Fish Lake valleys, had flooding and debris deposition in almost every "dip" along much of its course through the White Mountains; a typical example is shown in Figure 31. This highway was temporarily closed several times during the period 2 through 7 December 1966, but maintenance personnel worked around the clock to keep it passable and were, in general, successful.

(2) Morphologic Effects and Damage - South of Bishop (Figure 32)

Between Big Pine, California, and the extreme southern end of Owens Valley at Olancha, water and debris were across U.S. Highway 395 in about 30 places as a result of the heavy rains of 2 through 7 December 1966. At one site, 200 feet of roadway was completely cut away; in another, debris to a maximum thickness of almost 15 feet covered nearly 100 yards of highway. But most instances of flooding and debris deposition were less severe, with depths of water and mud generally between 1 and 2 feet. Highway 395 was closed to through traffic in southern Owens Valley for 5 days as a result of the floods.

I was unable to visit southern Owens Valley during the height of the runoff because U.S. Highway 395 was blocked at Big Pine, California, by flood discharge from the nearby Sierra Nevada. However, I visited the area on 8 December 1966 when cleanup and repair work were just getting underway. I paid greatest attention to the effects of runoff from the Sierra Nevada, although I made a brief reconnaissance of the western slope of the Inyo Range (the southern extension of the White Mountains) along which flooding was much less intense.

High runoff from lower Sierra Nevada slopes and adjacent alluvial fans, so far as I could judge a day or two after the event, tended generally to stay in or close to pre-existent channels. The primary morphologic effect of flood discharge appeared to be deepening of active channels on alluvial fans and distribution of the material thus removed farther down the fan surfaces. It was movement of this debris toward and into highway culverts and low places that brought about much of the damage. Indeed, plugging of culverts and consequent flow across or along the shoulders of the main valley-floor highway was responsible for by far the greatest amount of destruction. Figures 33 to 35 give views

(A)

(B)

Figure 30. Part of lower Poleta Canyon as it looked in 1956 (A), and as it appeared after the heavy rains of December 1966 (B).

Figure 31. Flooded "dip" on Westgard Pass road, showing depth of debris deposited by runoff of December 1966.

of typical damage in Owens Valley. Figure 36 shows what was left of part of a road through the Alabama Hills west of Lone Pine; in this case, the creek spilled out of its normal channel and flowed down the road for about 1/2 mile, excavating the roadway in places to a depth of 3 to 5 feet. Figure 37 is a picture of the cleanup job in progress on U.S. Highway 395 at a place 6 miles south of Lone Pine where debris to a thickness of nearly 15 feet accumulated along a 250 to 300 foot stretch of highway. Damage of the sort depicted in these views was widespread in Owens Valley, and although most of the primary roads were made passable in a matter of days, repair work was still underway in some places as late as August 1967.

The Los Angeles Aqueduct, as mentioned above, had six breaks in southern Owens Valley. In addition, an estimated 25,000 cubic yards of debris was dumped into the aqueduct in this area. As a result, the full flow of the lower Owens River, augmented by runoff from the heavy rains, returned to its old bed and discharged into the Owens Lake basin. Where the old channel is crossed by the Lone Pine-Death Valley highway, a few miles southeast of Lone Pine, the river overflowed its banks, flooding the highway to a depth of 10 to 12 inches over a distance of some 250 to

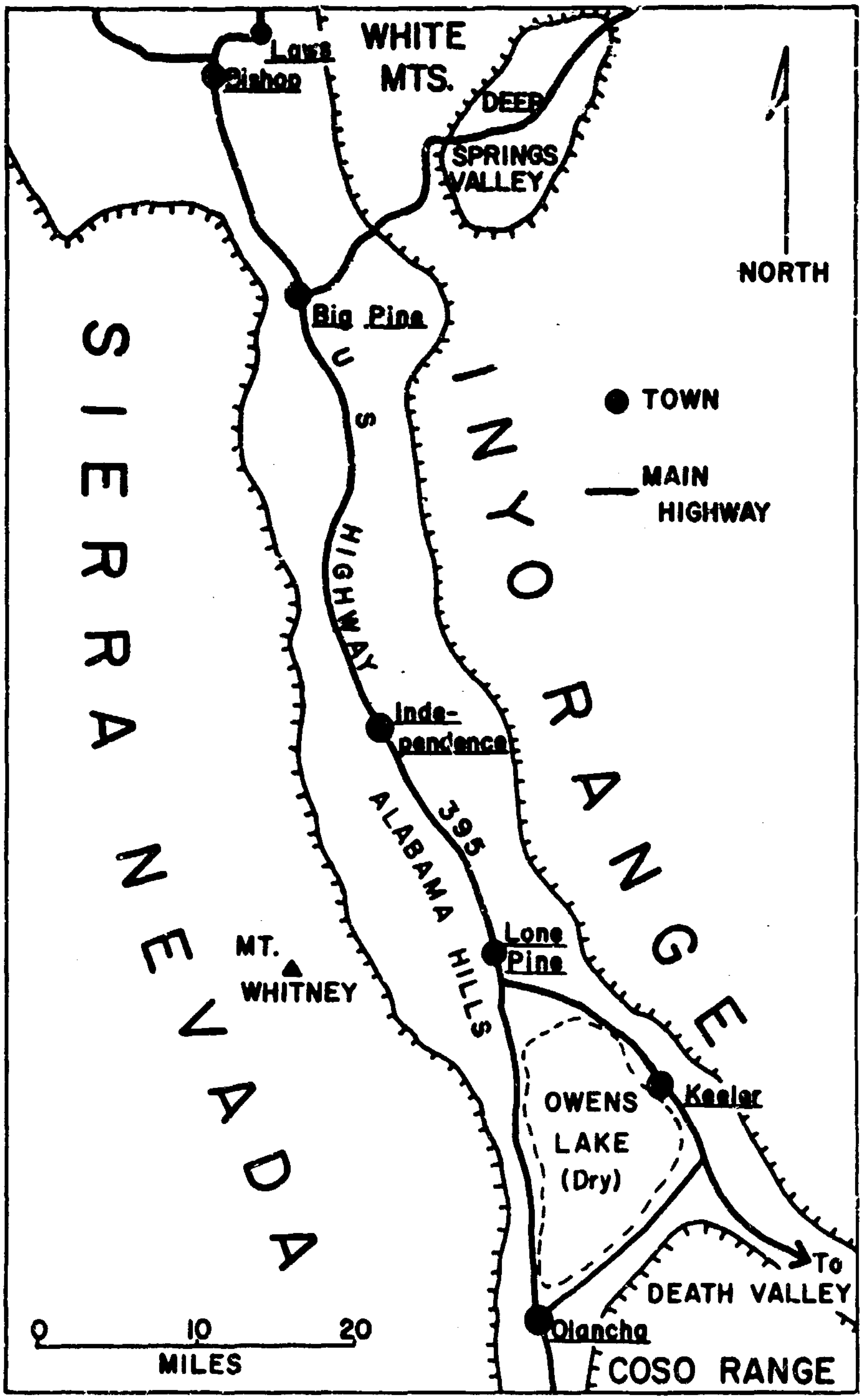


Figure 32. Index map of Owens Valley south of Bishop.

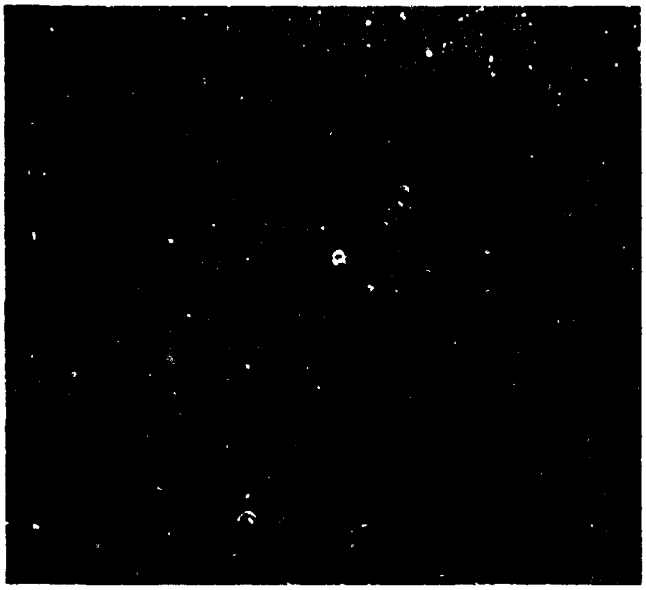


Figure 33. Flood damage to Death Valley highway about two miles southeast of Lone Pine.

Figure 34. Damage to U.S. Highway 395 between Olancha and Lone Pine. Snow-covered crest of Inyo Range on skyline.

Figure 35. Flood damage to county road east of Independence, central Owens Valley.

Figure 36. Tuttle Creek road through Alabama Hills, southern Owens Valley. About 2 miles of this county road had to be completely reconstructed after the floods of 1966.

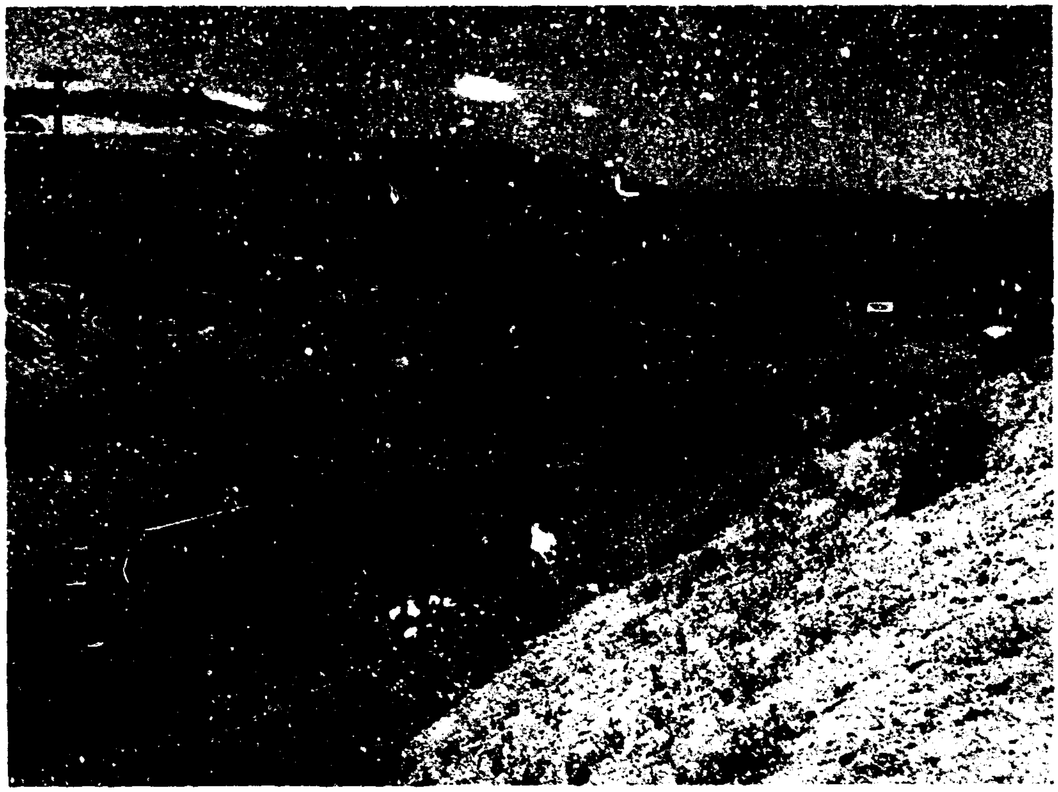


Figure 37. Flood debris from the Sierra Nevada over U.S. 395 south of Lone Pine.

300 feet (Figure 38). Traffic was slowed at this point but not halted.

Paved roads on the northeast and southeast sides of the Owens Lake basin were also damaged by heavy runoff. Water and debris to depths of 2 to 4 feet flowed through every "dip," and in two places short segments of the highway on the southeastern margin of the basin were cut away when culverts became plugged and the subsequent flow across the surface quickly eroded the roadbed.

Despite the widespread flood damage to primary and secondary roads in Owens Valley, the flow of traffic was about back to normal within a week or 10 days. However, state and county road crews were busy with repairs and reconstruction for many months, and it will probably be more than a year before all of the "back country" routes are restored to their pre-flood condition. Repairs to the Los Angeles Aqueduct were begun even as flooding was still going on. The Department of Water and Power of the City of Los Angeles, which operates the aqueduct, brought in a number of

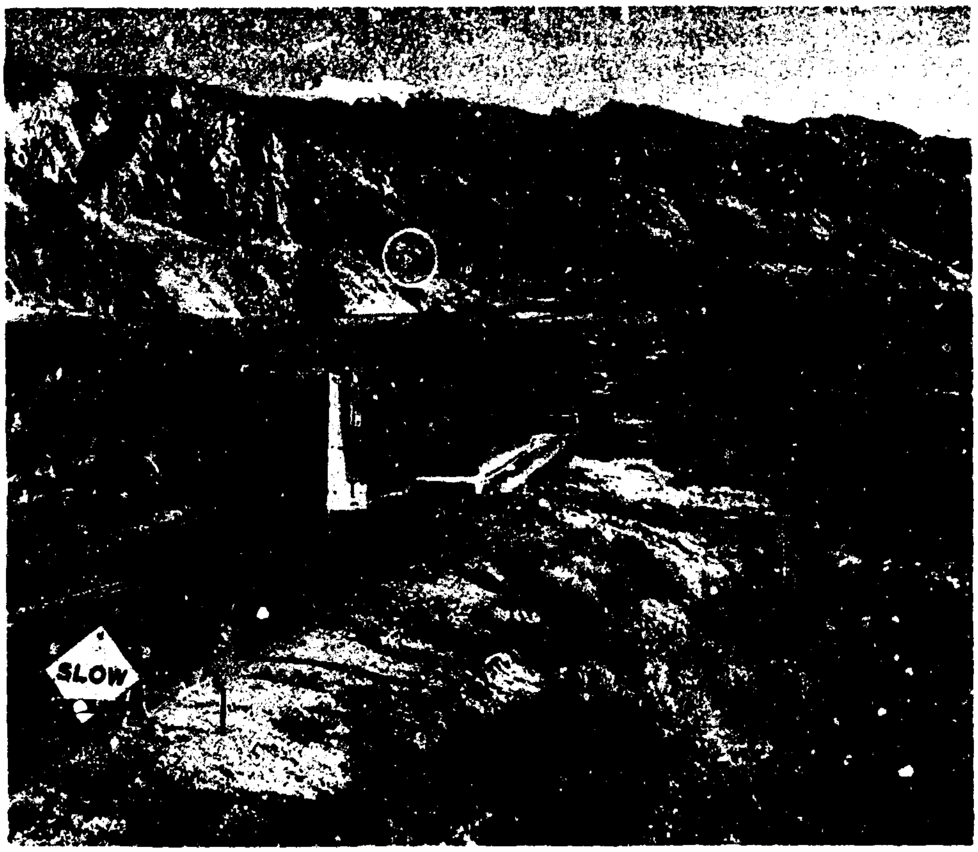


Figure 38. Owens River out of its banks and over California State Highway 135 about 3 miles southeast of Lone Pine, 8 December 1966.

extra units of heavy construction equipment to cope with the major tasks of clearing debris from the canal, rebuilding parts of the aqueduct road, and replacing short segments of the channel that had been destroyed. In less than two weeks the aqueduct was restored to service, although repair work continued along its course for many months.

(3) Summary

The Owens Valley floods of December 1966 represent a classic example of Wintertime Floods in the area of study. That is to say, they were caused by prolonged rains at lower elevations accompanied by heavy snowfall in the adjacent mountains. Their effects were limited principally to the floor of the main valley, although some damage was done to roads and structures in lower mountain canyons. The importance of temperature in determining runoff characteristics was well demonstrated in this case.

Had temperatures been higher, so that more of the precipitation fell as rain, lowland flooding would in all probability have been much more severe. Conversely, temperatures only a few degrees lower would have resulted in exceptionally heavy snowfall on the valley floor, which, if it had melted rapidly after the stormy period, could also have produced very destructive flooding.

Considering the large amounts of precipitation that fell during the period of flooding, the overall morphologic effects, at first glance, were unimpressive. However, the intensity of precipitation at no time could have approached that of the typical summer thunderstorm. Certainly if 5 to 10 inches of rain had fallen in only a few hours, the geomorphological results would have been startling, to say the least. But even at its heaviest, the widespread precipitation during 2 to 7 December must have had intensities well below 1 inch per hour, and the average intensity was undoubtedly much less than that. Consequently, although total runoff from lower mountain slopes and alluvial fan surfaces was great, its morphological effects were limited, in most cases, because of the prolonged period of time during which it was active. Concentration of runoff on and near the valley floor was responsible for the greatest amount of damage, and such concentration took place over a period of days, rather than hours.

b. Snowmelt Flooding, May and June 1967

The late spring snowpack in both the White Mountains and the southern Sierra Nevada was voluminous in 1967, with a water content that equalled or exceeded all-time records. Snow depths along the crest of the White Mountains in late April ranged from 40 to 50 inches in the south to nearly 90 inches in the central and northern sectors, and the snow cover at the northern end of the range extended almost to the valley floor (Figure 39). In addition to the large amounts of precipitation in early December 1966, the mountains received heavy snowfall in January, March, and April 1967. Furthermore, April 1967 was a particularly cool month, with average temperatures well below long-time means, as a result of which significant melting of the deep snowpack began about a month later than usual. In short, conditions seemed very favorable for serious snowmelt flooding, and the California Department of Water Resources predicted an April-September runoff in the eastern Sierra region of 160 percent of the long-time normal (Inyo Register, 27 April 1967).

White Mountains

In the White Mountains, a meaningful weather change occurred during the second week of May 1967, when daily high temperatures on the floors of the adjacent valleys rose to the 80's and 90's. At the two University of California laboratories on the crest of the range, daily maxima climbed from several degrees below freezing to the 40's and middle 50's at this time, and detectable snowmelt runoff reached the margin of the mountains

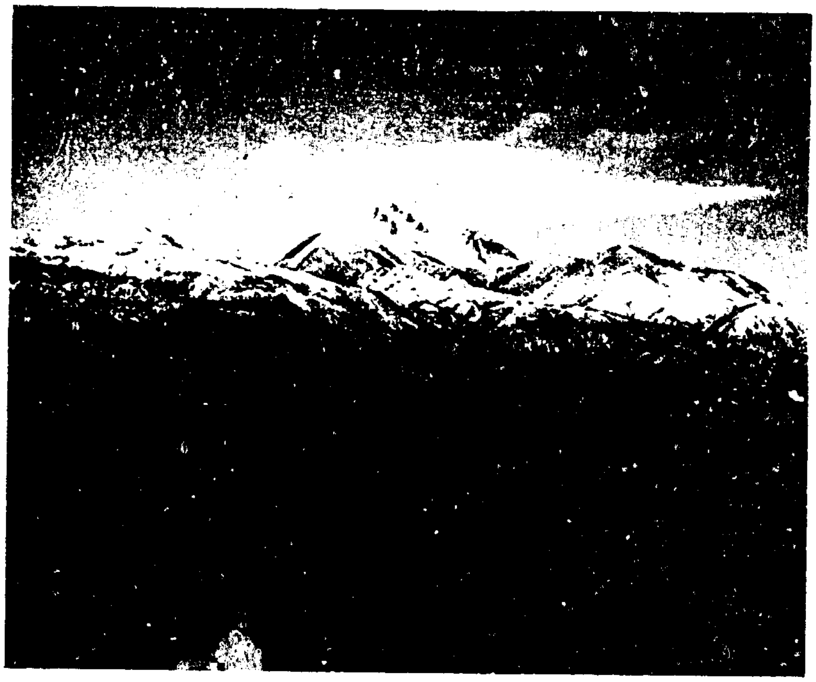


Figure 39. Northern White Mountains from Montgomery Pass highway, 25 April 1967.

on approximately 15 May. Warm weather continued for about 10 to 12 days, during which moderate snowmelt flooding took place on both sides of the range. The last few days of May and the first two weeks of June were cool, with a couple of periods of precipitation in the mountains during which several inches of fresh snow were added to the diminishing snowpack. After this, warm weather returned, and a second episode of snowmelt flooding occurred, lasting from about 19 June to 26 June.

Behavior of snowmelt runoff in the White Mountains during May and June 1967 was remarkably similar to what I observed in 1957 (see detailed discussion in Kesseli and Beaty, 1959, p. 60-68). Only those drainages which have had serious flooding with debris flows in the last two decades were affected; most other streams on both sides of the range underwent a gradual, hardly noticeable rise in discharge. The pattern of flooding was essentially the same in all cases. Lack of a continuous "sponge" of alluvium and colluvium on trunk canyon floors permitted each afternoon's snowmelt quickly to reach the edge of the mountains, and great variations between maximum and minimum discharge occurred. As in 1957, maximum discharge was observed in the early morning hours, while minimum flow passed canyon mouths early in the

afternoon. As in 1957, pipeline intakes in lower canyons were washed away or plugged with finer debris, and ranches dependent upon surface water for irrigation purposes were deprived of this for more than a week. Finally, as was also true in 1957, high discharge reached and flooded valley-floor highways in both Upper Owens and Fish Lake valleys, slowing but not stopping the flow of traffic.

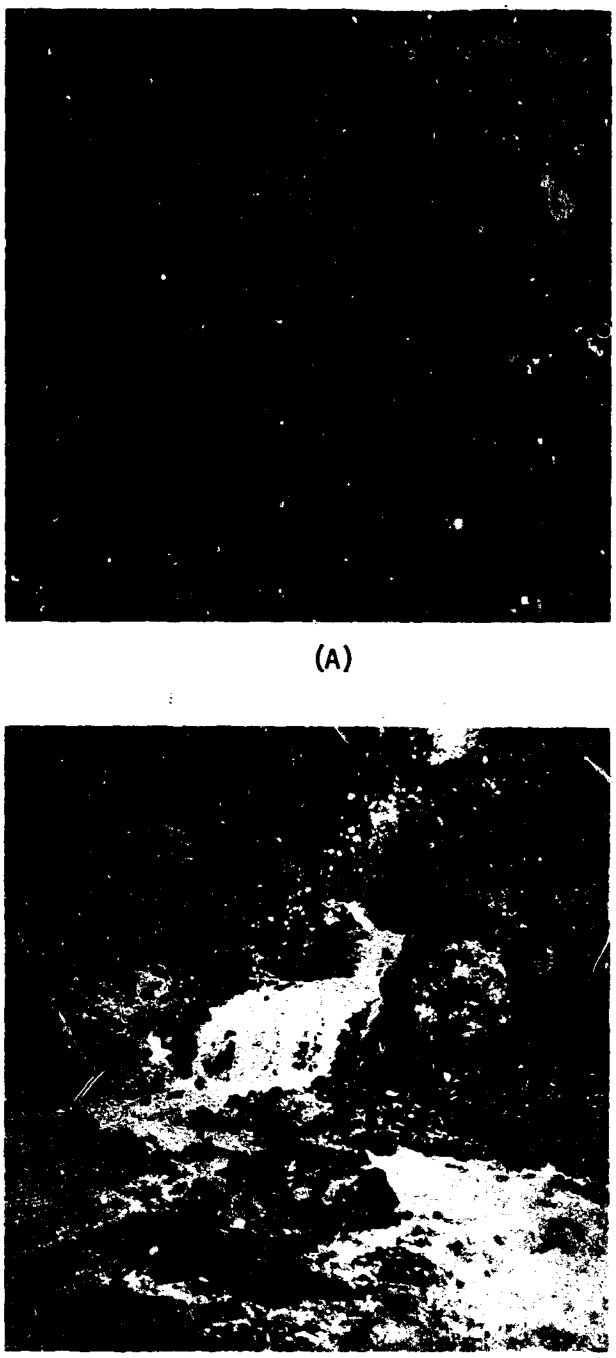
Four stream systems provided most of the higher-than-normal runoff during the two episodes of snowmelt flooding in 1967: Milner Creek, Lone Tree Creek, and Cottonwood Canyon on the west, and Leidy Creek on the east flank of the White Mountains. As noted earlier in this report, these are the same drainages that experienced major debris flows in 1952. They have apparently had snowmelt flooding almost every year since that time, and there seems little reason to doubt that they will continue to be "troublemakers" in the future.

Other drainages on both sides of the range, during the periods of high water in the stream systems just mentioned, were undergoing only a very slow increase in discharge and an equally gradual return to normal. The "sponge" effect of alluvial and colluvial fill on trunk canyon floors, observed in the past in the White Mountains, is here held responsible for the relatively tranquil behavior of these stream systems. Even Montgomery Creek and Sparkplug Canyon, both of which had major debris flows during the 1957-66 decade, showed little evidence of the effects of high snowmelt runoff. It is believed that these two drainages did not undergo significant snowmelt flooding in 1967 because both still have considerable volumes of alluvium and colluvium on the floors of their lower trunk canyons. Even though they have produced sizable debris flows in the recent past, they retain sufficient unconsolidated valley-floor fill for the "sponge" effect to be operative.

Comparison of pictures taken in 1957 and 1967 suggests how similar the behavior of snowmelt flooding was in these two years. Figures 40 through 42 show flood waters at three different sites, as seen a decade ago and again in the late spring of 1967; except for a few minor differences, the pictures are virtually interchangeable.

Sierra Nevada

Governmental agencies charged with land management in the Owens Valley area were justifiably concerned in 1967 about the possibility of major flooding problems brought about by snowmelt runoff from the Sierra Nevada. Whereas the White Mountains snowmelt floods directly affected only a few people, massive discharge from the eastern slopes of the Sierra Nevada could have created much bigger problems. Despite somewhat dire public predictions, however, runoff from the eastern Sierra slope did not reach disastrous proportions, nor were major damages reported. The Department of Water and Power of the City of Los Angeles, which manages the Owens River system, so manipulated storage and runoff that most of the excess



(A)

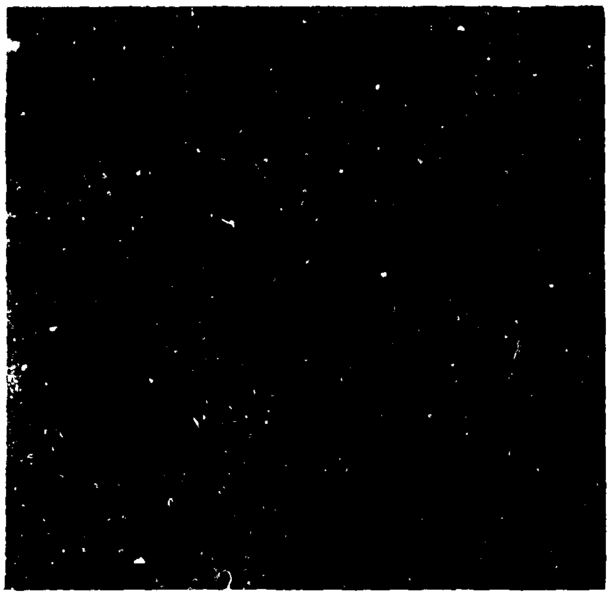
(B)

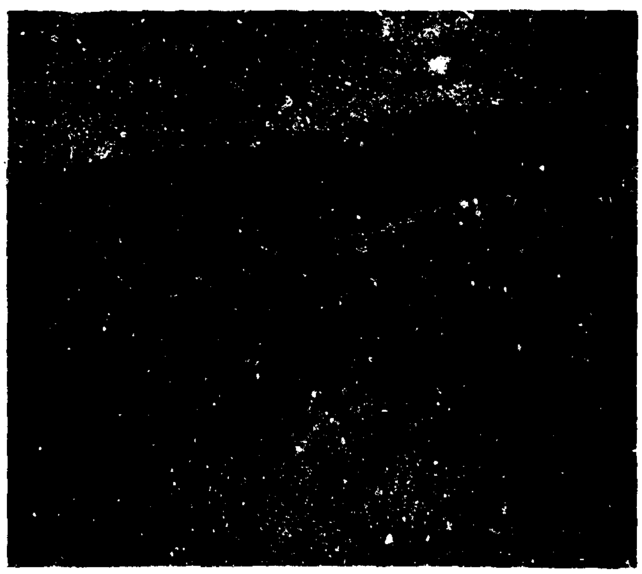
Figure 40. Snowmelt runoff coming over pipeline intake box in Milner Creek Canyon. (A) June 1957; (B) May 1967. Flow in 1957 was somewhat greater and much dirtier, but the general behavior of flood waters was essentially the same in both years.

(A)

(B)

Figure 41. Snowmelt runoff from Lone Tree Creek over U.S. Highway 6 in Upper Owens Valley. (A) June 1957; (B) same place, May 1967.





(B)

Figure 42. Snowmelt runoff from Leidy Creek over highway on floor of Fish Lake Valley, east of the White Mountains. (A) June 1957; (B) 200 yards north, June 1967.

flow could be diverted onto unused flat areas in Owens Valley, where presumably much of the water percolated downward to join the underground reservoir. North of Owens Valley, runoff from the Mono Basin was dumped into Mono Lake, rather than being piped to the Owens River by way of the Mono Craters tunnel. Higher-than-normal discharge persisted in Sierra Nevada streams throughout most of the summer of 1967, but the anticipated serious lowland flooding failed to materialize. Some damage was sustained, of course. A few bridges were washed out in the mountains, irrigation ditches were silted up or cut away in places, and the shoulders of highways and secondary roads were eroded. At least one death was attributed to snowmelt flooding, when a resident of the area was drowned while attempting to cross a swollen Sierra Nevada stream on horseback. But the record snowpack of 1967 did not generate the major floods predicted because of its late spring water content. Two meteorological factors seem to have accounted for the lack of destructive flooding: (1) nights remained fairly cool in the high Sierra Nevada during the period of most active melting; (2) few really heavy rains fell during that time. Had higher-than-normal nighttime temperatures been accompanied by copious thunderstorm rain, snowmelt flooding in Owens Valley undoubtedly would have been much more severe and destruction of roads and other man-made features widespread.

c. Cloudburst Flooding, July and August 1967

July and August 1967 were wet months in the White Mountains area. July precipitation at the two University of California laboratories on the crest of the range exceeded previously recorded highs; the Mount Barcroft station received 4.50 inches, all rain, while the Crooked Creek laboratory measured 4.02 inches. The July total of .62 inch at Bishop, California, was also a new record for the month. Considerable July precipitation was recorded at most of the other official weather stations in the area, and a number of the gages that I maintained caught sizable amounts of rain (see Appendix for station totals). August precipitation was less than that in July, but the amounts that fell along the crest of the White Mountains were well above the long-time means.

Three episodes of cloudburst flooding occurred in the White Mountains during July and August, two relatively minor, the third much more severe. Although there was notable movement of material on trunk canyon floors within the mountains and in active channels on alluvial fans, in none of the instances of flooding was precipitation sufficiently intense to produce a debris flow. I did not observe any of the floods at its height; however, I did visit all the affected areas within a matter of hours after flooding.

(1) Flood of 6 July 1967 - Deep Springs Valley

On the afternoon of 6 July 1967 an extremely heavy rain, falling from an isolated thunderstorm cell, moved across the north end of Deep Springs

Valley, northeast of Big Pine, California. During the period 1440 to 1520 hours, .75 inch of rain accumulated at the weather station operated by the Deep Springs School, near the northeast end of the valley. A small cloudburst flood developed in the White Mountains foothills on the northwest side of the valley, flowing down one side of an alluvial fan and depositing 12 to 15 inches of mud on the paved highway along the northwest margin of the valley (Figure 43).

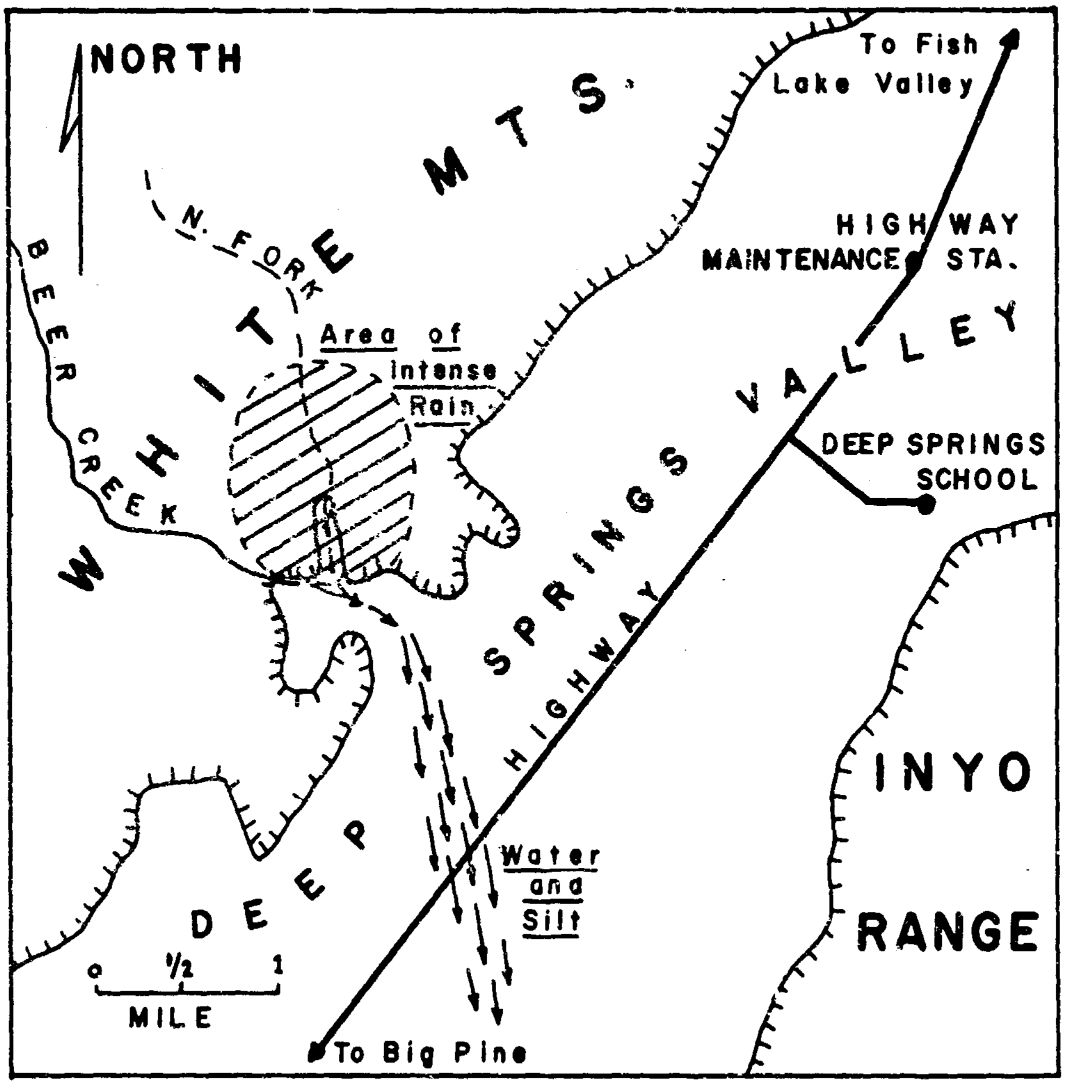


Figure 43. Sketch map of minor cloudburst flood in Deep Springs Valley, 6 July 1967. Base: U.S.G.S. 15-minute Blanco Mountain and Soldier Pass topographic quadrangles.

I visited the site about 1-1/2 hours after the event, and although at that time small amounts of water were still running across the highway (Figure 44), most of this had stopped. I located one eyewitness,

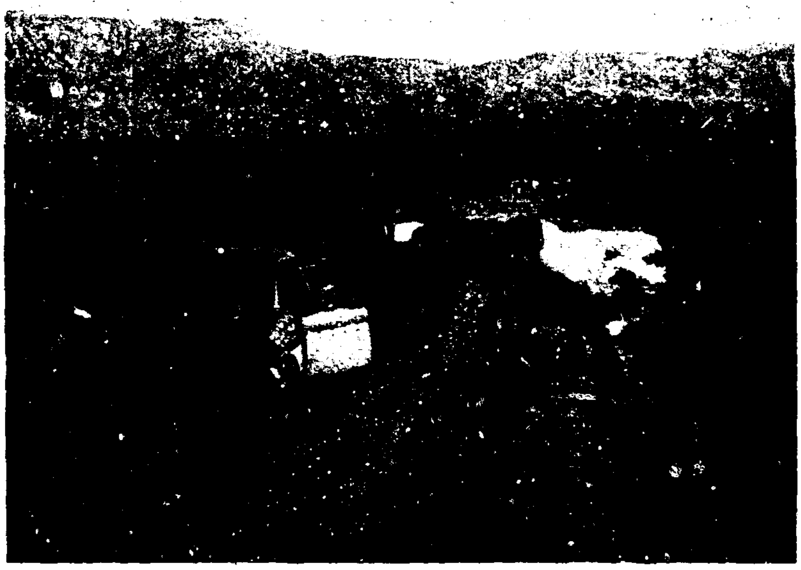


Figure 44. Runoff from minor cloudburst flood across highway in Deep Springs Valley, 6 July 1967.

an employee of a state highway maintenance station in Deep Springs Valley, who was even then preparing to clear debris from the roadway. This man had watched the intense rain from a distance of about 3-1/2 miles and described it as the "heaviest I have ever seen" (Azavedo, L., personal communication, 1967). According to Mr. Azavedo, the torrential downpour completely obscured the mountains for about 20 to 25 minutes, after which the most intense concentration of precipitation moved slowly eastward across the valley floor and over the Deep Springs School. As the rain slackened, Mr. Azavedo noticed a "low, frothy wall of water, lightish in color," moving out of the mountains and down across the alluvial fan toward the highway. The muddy water "fairly boiled" across the highway, with an estimated depth of 18 to 20 inches; flow of this depth continued for about 10 minutes, then quickly shallowed to only a few inches. As the runoff subsided, silt was deposited on 300 to 400 feet of roadway; the whole incident took perhaps 35 to 40 minutes.

The next day I visited the small catchment basin out of which most of the runoff had come. Overland flow down the margin of the alluvial fan had followed an old, unpaved road, which was badly eroded in places (Figure 45). At the fan apex, water in the active channel had attained

Figure 45. Gravel road on alluvial fan in Deep Springs Valley eroded by cloudburst flood of 6 July 1967.

depths of at least 3 to 4 feet, and boulders up to 15 inches in diameter seemed to have been moved. Within the mountains, in what appeared to have been the zone of most intense precipitation, slopes were cut and gullied in spectacular fashion (Figure 46), and there was much evidence of debris movement toward and into the main channel on the floor of the affected canyon. Careful examination of adjacent, ungullied slopes established the fact that the area of heaviest rain had covered little more thar a square mile.

Although it is impossible to state with absolute precision what the intensity of precipitation may have been in this case, at least one can make an informed estimate. As noted above, .75 inch of rain fell in about 40 minutes at the Deep Springs School, corresponding to an intensity of slightly more than 1 inch/hour. Slopes immediately behind the school were not gullied by rain of this intensity, whereas slopes similar in both lithology and average inclination in the catchment basin providing

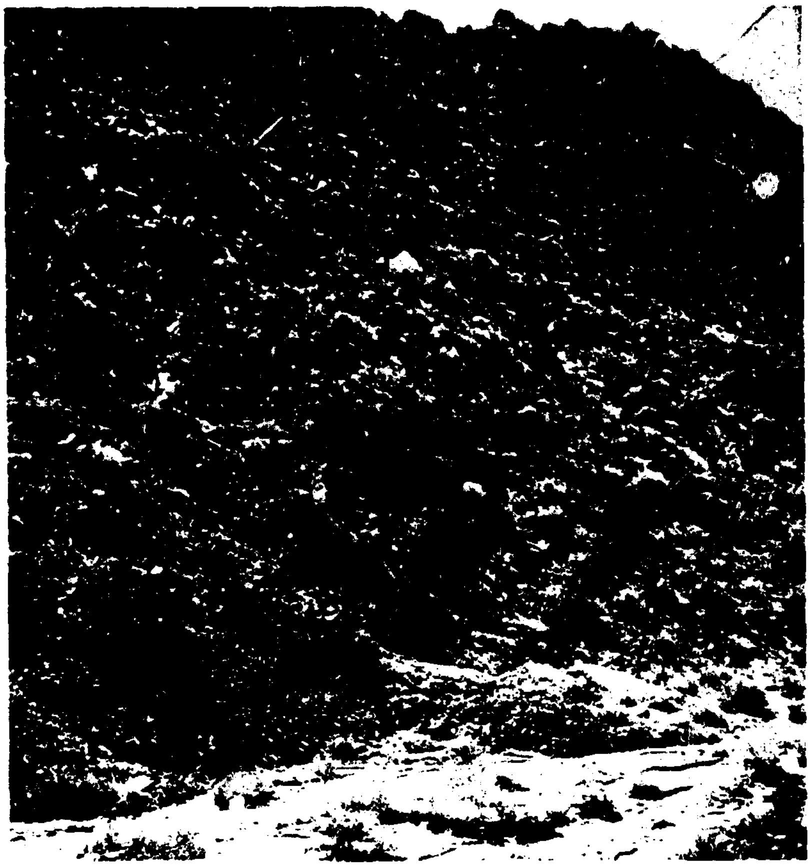


Figure 46. Slope in catchment area gullied by cloudburst flood of 6 July 1967 in Deep Springs Valley. Debris cone on channel floor (arrow) was deposited by runoff from heavy rains on that date.

the flood were badly eroded. It seems probable that the short-time intensity within the affected drainage basin must have greatly exceeded that received at the Deep Springs School and may have approached several inches an hour. If the area of most intense precipitation had been larger, or if the heavy rain had fallen for more than the observed 20 to 25 minutes, undoubtedly a major flood and possibly a debris flow would have developed. As it was, brief, torrential precipitation in a very limited area resulted in flood runoff of sufficient depth to stop traffic on a main road, although for only a relatively short period of time.

(2) Floods During Period 12 to 16 July 1967

Thunderstorm activity was general in the White Mountains during this 5-day period, with locally intense rain on several occasions. Flooding occurred in at least 5 individual drainage systems within the range, all of which I visited within a few hours of the time of highest runoff.

Milner Creek and Lone Tree Creek

Heavy rains fell along the western flank of the White Mountains on the evening of 12 July. Measured catches on an east-west traverse from Mount Barcroft to the western base of the range were: Mount Barcroft (elevation 12,470 feet) - 1.15 inches; 9,000 feet - .26 inch; 5,500 feet - .02 inch. At the Mount Barcroft laboratory most of the precipitation came between 1800 and 2000 hours, with nearly .50 inch falling between 1830 and 1900 hours. Surface runoff in Milner and Lone Tree Creeks began to increase significantly in volume at about 2130 hours, and by 2400 hours water was flowing across alluvial fans to the highway on the floor of Upper Owens Valley. The flow from Milner Creek was contained by two large culverts, but runoff from Lone Tree Creek washed over the highway in about the same place that had been affected by snowmelt flooding earlier in the year (Figure 47). Minor flooding of U.S. Highway 6 at this point continued for the next three days, as more thunderstorm activity developed in the mountains.

Rains of 13 July

The heaviest measured rains during the summer of 1967 in the White Mountains came on 13 July. Recording precipitation gages at three sites on the crest of the range (Mount Barcroft, Crooked Creek laboratory, and Schulman Grove) caught considerable amounts of water on that date. Their graphs make possible a reasonably good reconstruction of the movement of the zone of most intense precipitation in the highlands. On 13 July I had gone to an area along the western flank of the mountains north of Bishop, since from the valley floor the cumulus buildup over that part of the range looked most promising for flood-producing rains. Significant flooding occurred in the White Mountains on the evening of 13 July, but not, unfortunately, where I had thought it likely. Thus I lost probably the best opportunity during the study period to observe cloudburst flooding in action.

Heavy rains began in the northern White Mountains about noon on 13 July. The area of most intense precipitation moved slowly toward the south during the afternoon. Precipitation figures from the three recording gages are instructive in this regard:

1. At the Mount Barcroft station, 1.48 inches of rain fell between 1230 and 1930 hours, with .80 inch coming from 1400 to 1510 hours.

Figure 47. Runoff from Lone Tree Creek across U.S. Highway 6 in Upper Owens Valley, early morning of 13 July 1967. Minor flooding was produced by heavy rains on evening of 12 July 1967.

2. At the Crooked Creek laboratory, 2.40 inches of rain fell from 1440 to 2000 hours, with 1.20 inches accumulating between 1440 and 1540 hours.

3. At the Schulman Grove locality, a total of 2.92 inches fell between 1540 and 2200 hours, with 2.00 inches during the period 1540 and 1740 hours.

Rainfall totals for 13 July from nearby valley stations are of interest. Bishop, west of the White Mountains, had .48 inch. Deep Springs School, south of the area of heaviest precipitation, had .24 inch. Dyer, Nevada, on the floor of Fish Lake Valley, to the east of the range, had .[illegible] inch. At all these stations the rains came late in the afternoon or the early evening, generally between 1700 and 2000 hours. Montgomery Pass, at the north end of the White Mountains, recorded only .02 inch on 13 July.

Westgard Pass Area

As a result of the heavy rains, flooding of moderate intensity developed in at least two drainage systems in the southern White Mountains. The Westgard Pass highway, leading from Big Pine, California, to Deep Springs Valley and beyond, follows the floor of an unnamed drainage to the crest

of the range at Cedar Flat and winds to the bottom of Deep Springs Valley by way of Payson Canyon. Water and debris to depths of 3 to 4 feet ran down or close to this highway on both sides of the range, flooding every "dip" in the roadway for a distance of about 8 miles. According to an observer who was caught in the runoff on the west side of the pass, boulders up to 2 or 3 feet in diameter were being rolled across the highway in some of the "dips," although most of the solid material in transit was much finer (Newell, J., personal communication, 1967). The greatest runoff in the area seems to have come between 1800 and 2130 hours. As a safety measure, the road was closed to public travel by the California Division of Highways during the night of 13-14 July. However, when I visited it early on the morning of 14 July it was passable, since cleanup work had been underway throughout the night. Most of the "dips" had been cleared of debris by then (Figure 48), although deeper accumulations were

Figure 48. "Dip" on Westgard Pass road, southern White Mountains, flooded on evening of 13 July 1967.

still being removed (Figure 49).

Also north of Westgard Pass, along the road on the crest of the White Mountains, the rains of 13 July produced minor flooding. Considerable amounts of finer debris were washed onto the surface in many places, and literally thousands of pinyon pine cones were strewn over the road (Figure 50). Little serious damage was noted here, and the road was quickly cleared by county crews.

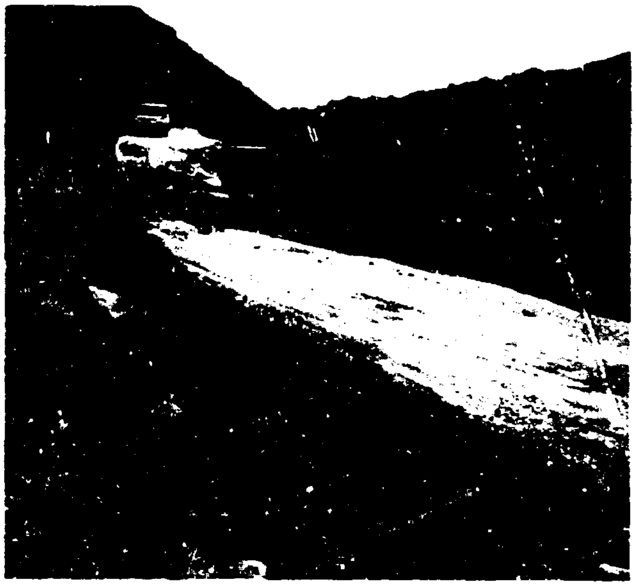


Figure 49. Cleanup work on Westgard Pass road, morning of 14 July 1967.

Black Canyon

While the Westgard Pass area was being flooded on the evening of 13 July, the nearby Black Canyon drainage system was also discharging heavily. Black Canyon proper rises near and south of Reed Flat on the crest of the White Mountains; about 1-1/2 miles above its mouth it is joined by Marble Canyon. During the heavy rains of early December 1966 the Black Canyon drainage system produced significant runoff, but most of the water in that flood came from the Marble Canyon branch of the system. In contrast, the cloudburst of 13 July 1967 resulted in much greater runoff from the main Black Canyon; although some surface flow accumulated in the Marble Canyon catchment basin on this occasion, by far the greater amount came from Black Canyon itself.

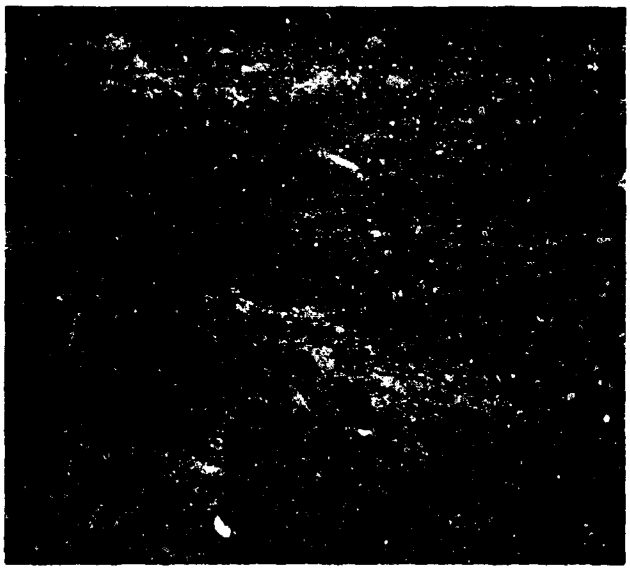
The major morphologic effect of the flood in Black Canyon was the shifting of moderate amounts of unconsolidated debris on the canyon floor toward and onto the alluvial fan at its mouth. In the middle segment, above the junction with Marble Canyon, as much as 4 to 6 feet of alluvial and colluvial fill was cut away in places. A road on the canyon floor that had been in existence at least 50 years was totally destroyed over a distance of 2 miles. In this part of the canyon, water and debris attained depths of 5 to 6 feet in narrow reaches, and boulders up to 4 feet in diameter were moved. In the lower canyon, where spreading of

Figure 50. Debris and pine cones on White Mountain crest road, morning of 14 July 1967.

the flood waters was possible, the primary morphologic processes during the flood seem to have been scouring and filling of the channel floor, by which debris was moved toward and beyond the mouth of the canyon. Figure 51 A and B presents pictures of lower Black Canyon taken in 1957 and 1967 respectively. The most evident change during the decade, brought about primarily by the flood of 13 July 1967, has been the reworking of unconsolidated material on the channel floor, as a result of which much of the vegetation in the normally dry active channel has been destroyed.

Figure 52 is a low-altitude aerial view of the Black Canyon alluvial fan, taken four days after the flood. Fresh material deposited on the fan surface is represented by the strips and patches of lighter color, visible on the central part of the fan. A closer view of the fresh debris (Figure 53) indicates the average size of material transported from the mountains; most of it was fist-sized or smaller, although here and there an occasional larger boulder can be seen.

(A)



(B)

Figure 51. Lower Black Canyon, with Owens Valley and Sierra Nevada in background. (A) View in 1957; (B) same scene, July 1967.

Figure 52. Aerial view of Black Canyon alluvial fan showing fresh debris deposited by flood of 13 July 1967.

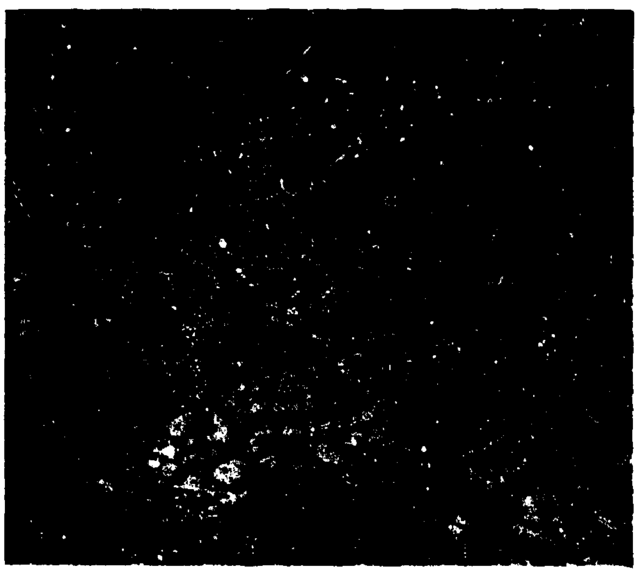


Figure 53. Flood debris on alluvial fan of Black Canyon, July 1967. Tripod is about 16 inches long.

Leidy Creek and Fish Lake Valley

On the eastern flank of the White Mountains and in adjacent lowlands in western Nevada, heavy rains were also falling during the period 12 to 16 July 1967. Minor flooding of roads in the vicinity of Fish Lake Valley was widespread, with water and fine debris across most "dips" and other low places. At no time, however, were the roads closed to traffic; depths of water and debris on surfaces generally were shallow, in most cases no more than a few inches, and cleanup work proceeded almost as rapidly as flooding took place.

In Leidy Creek, which had sustained snowmelt flooding earlier in 1967 (and probably in most years since 1952), significant cloudburst flooding did occur, probably on the night of 15 July. The date is in question because I couldn't find a reliable eyewitness to the event. In this drainage, discharge during the first 10 days of July was relatively high because the snowpack in its headwater area, near the crest on the eastern flank of the White Mountains, was still quite deep and yielding considerable meltwater. Heavy rains were recorded at Mount Barcroft (the weather station closest to the headwaters of Leidy Creek) on 12, 13, and 15 July, and it was the best recollection of somewhat doubtful witnesses that "nothing much had happened on the 12th or 13th." In any event, high runoff developed in lower Leidy Creek, and enough debris was moved on the bed of the flooding stream to fill completely a small reservoir at a pipeline intake 1/2 mile within the lower canyon (Figure 54). A building at one end of the reservoir dam was partially buried and the pipeline equipment within submerged beneath 3 feet of rubble. Little of the debris that was shifted within the lower canyon of Leidy Creek seems to have been transported to the alluvial fan, but the silty water that flowed down the active channel scoured its floor as much as 3 to 4 feet in places and left 12 to 15 inches of mud over about 500 feet of the highway in Fish Lake Valley.

At the same time, other drainages on the east flank of the White Mountains were experiencing higher-than-normal runoff - although not flooding - generated by the heavy rains along the crest. Added to the later-than-usual snowmelt still coming off the eastern slope of the range, storm runoff from all of the larger streams united on the floor of Fish Lake Valley and followed an old channel system toward the playa at its northern end. For the first time in many decades, enough water accumulated on the playa to spill over the low divide at the northern end of Fish Lake Valley and into the adjacent Columbus Salt Marsh basin. Sluggish surface flow from the Fish Lake Valley playa to Columbus Salt Marsh lasted about 48 hours (Nurmi, J., personal communication, 1967).

(3) Minor Flooding, 9 August 1967

Thunderstorm activity in the White Mountains region was widespread but very sporadic in time and place during August 1967. In that month I heard of only one minor flood. Late on the afternoon of 9 August, McAfee Creek,

Figure 54. Pipeline intake reservoir in lower Leidy Creek Canyon filled and partly destroyed by flood of July 1967.

on the eastern slope of the White Mountains, was reported to have flooded moderately, producing enough runoff on its alluvial fan to put 8 to 10 inches of water and fine debris across a short stretch of the Fish Lake Valley highway. When I visited the area early the next morning, almost all evidence of the flood was gone. Highway maintenance personnel had cleaned up the roadway, and the creek at the mouth of McAfee Canyon was running clear and low. Precipitation in the White Mountains was spotty

on 9 August, and one can only assume that an isolated thunderstorm cell happened to have centered over the McAfee Creek catchment basin that afternoon. The Mount Barcroft weather station (closest to upper McAfee Creek) had no precipitation on that date. On the other hand, the Crooked Creek laboratory received 1.32 inches of rain between 1400 and 1800 hours on 9 August. The Crooked Creek station is about 8-1/2 air-line miles south of the headwaters of McAfee Creek.

(4) Summary

Although cloudburst flooding in the White Mountains during the summer of 1967 did not reach catastrophic proportions, I believe that the observations I was able to make have both theoretical and practical value. In the first place, lack of major floods accompanied by massive debris flows is probably a far more typical summertime situation in the American Great Basin than is the opposite. I believe that conditions favorable for the development of a debris flow are rather special and restrictive: intense rain has to be concentrated in a single drainage system, the trunk canyon of which must be steep, narrow, and floored with unconsolidated alluvium and colluvium (Kesseli and Beaty, 1959, p. 92). The White Mountains undoubtedly possess drainage systems with the necessary morphologic characteristics, but it would be expecting too much to think that precisely the necessary meteorological conditions will prevail every year. The flooding history of the White Mountains during the summer of 1967 is very likely much closer to the "average" than would be that of a season in which several spectacular debris flows occurred.

A second matter of interest relating to observations made in 1967 has to do with measured precipitation intensities. On several occasions, accurately measured rainfall intensities of greater than 1 inch/hour were recorded. In all of these instances, higher-than-normal runoff quickly developed in the affected drainage basins. But in no case was a debris flow generated. Flooding of the high-water type evolved and significant erosion was accomplished on canyon floors and in active channels on alluvial fans, but massive transfer of debris from the mountains to the adjacent lowlands failed to materialize. It follows that in the White Mountains, at least, intensities much greater than those measured during 1967 must be necessary for serious debris flowage to take place.

Finally, I must comment on the geographical distribution of flooding in the White Mountains during summer 1967. Throughout the period of settlement in this area there has been a recognizable concentration of reported cloudburst floods along the central sector of the western flank of the range (Kesseli and Beaty, 1959, p. 30-32). Kesseli and Beaty concluded in their 1956-57 study that "...the distribution of observed floods will show concentration and lack of concentration in direct relation to the density of settlement and the frequency of travel on the major roads of an area" (Ibid., p. 31). The statement is probably accurate for a fairly sizable area over a period of many years. I am no longer so

sure of its applicability to the White Mountains or to any comparable individual desert range in a single given year. Certainly the geographical pattern of 1967 summer flooding in the White Mountains was decidedly different from the "average," as determined by examination of the historical record. It is recognized that the "average" in this case, as is true of so many other "averages," may well represent a gross distortion of reality. In any event, an attempt to predict where flooding might have occurred in the White Mountains during summer 1967, based upon reported flooding behavior in the past, would have failed rather decisively. In effect, on the afternoon of 13 July 1967 I "predicted" that serious flooding would take place in the central part of the western side of the range; this "prediction" proved wrong, although at the time it seemed logical and compelling. The point being made is simply that in a given year there would seem to be no point in trying to outguess nature, at least so far as predicting the exact location of serious flooding.

PART III

CONCLUSIONS

1. Principles established by study of 1956-57

As a result of the field investigation of 10 years ago, a number of fundamental conclusions regarding desert flooding and its potential dangers were reached (Kesseli and Beaty, 1959, p. 83-99). Summarizing briefly, these were:

(1) The relative flooding probability of any desert stream system depends upon (a) the morphologic characteristics of the drainage basin and its alluvial fan and (b) the climatic characteristics of the area in which the drainage is located.

(2) Since it is almost impossible to predict with precision when and where a flood-producing rain may fall, the most productive way to determine the flooding potential of a given drainage system should be carefully to study and evaluate the physiographic features of the drainage basin and its associated alluvial fan.

(3) The most dangerous drainage systems in a desert range are those heading in the highest part of the range, the trunk canyons of which are steep, narrow, and floored with unconsolidated alluvial and colluvial fill. Such canyons are apt to produce serious floods, some of which may be accompanied by debris flows, that can advance far out onto the subjacent alluvial fans.

(4) Morphology of alluvial fans is a useful guide to flooding probability. Generally, in the White Mountains and elsewhere steep alluvial fans are found below steep canyons in a desert range. The slope of a fan is thus an easily established first indicator of the probability and possible severity of floods which issue from the associated canyon.

(5) Major debris flows in the White Mountains during the past 100 years have come only from canyons designated as having the Falls Canyon type of profile, i.e., canyons that are extremely steep from headwater area to mouth.

(6) Flooding of the high-water type, without associated debris flows, has occurred at all times of the year in the White Mountains and has been caused by summertime thunderstorms, winter frontal rains, and snowmelt during late spring and early summer. Steep canyons which have recently had alluvial and colluvial fill removed by large debris flows are particularly susceptible to flooding of this type, although under favorable meteorological conditions, high-water flooding may occur almost anywhere within or adjacent to a high desert range.

(7) Evaluation of the safety of a given site on a desert alluvial fan or in a canyon can be only relative. Nevertheless, observations of past flooding behavior, as shown by the morphologic evidence, can yield some useful general principles of site safety. Most canyon floors must be considered unsafe for all but the most temporary uses. Even moderate flooding can be dangerous and potentially destructive in a steep, narrow canyon. Some desert canyons have alluvial terraces in their lower courses, and these can be considered areas of relative safety, especially if they stand more than 15 to 20 feet above the canyon floor. On an alluvial fan, the most dangerous area is a radial strip including and flanking the active channel; the upper and lower thirds of a fan are considered to be moderately dangerous, while the middle third of the fan is subject only to slight flood danger.

(8) An estimation of the potential flooding danger of any site in mountainous desert terrain should be based upon the following steps:

a. An examination should be made of each drainage basin above the area contemplated for use to determine:

(1) its profile type
(2) the width of its trunk canyon
(3) the depth of alluviation of its trunk canyon.

A consideration of these three morphologic factors should lead to an estimate of the flood hazard, as well as the type of flooding to be expected in the event of heavy rain or excessive snowmelt, that is, whether they would cause debris flows or result only in high water flows.

b. An examination should be made of the alluvial fan or bajada to determine:

(1) the location of the active channel(s)
(2) the depth of incisement of the active channel(s)
(3) the zone of most recent flooding on the surface as indicated by freshness of deposits or channel cuts, and therefore the area of most probable future flooding
(4) the channel pattern on the fan or bajada surface

With these facts in hand, it will be easier to select the safest site on the fan or bajada.

It cannot be stressed too strongly that a careful field examination should be made of the area which it is planned to use. There is no adequate substitute for such an investigation if the wisest and safest land use is to be achieved.

2. Flooding in White Mountains, 1957-67, in light of principles established in 1956-57.

Floods in the White Mountains during the decade 1957-66 and those I observed during the 1966-67 period of field study were of the three types known to occur in this area: Wintertime, Snowmelt, and Cloudburst floods. Two major debris flows took place in the period, one a typical cloudburst phenomenon, the other apparently generated by snowmelt runoff; a third - but minor - debris flow was probably caused by a summer thunderstorm.

Snowmelt flooding has been almost a yearly occurrence in certain drainages in the range, and the heavy rains of early December 1966 produced widespread lowland flooding, particularly in Owens Valley.

In general, all flooding behavior I observed or was able to verify conformed to the principles established by the study of 1956-1957. The three debris flows came from drainage systems with trunk canyon profiles of the Falls Canyon type. Two of them - those in Montgomery Creek and Willow Creek - were caused by heavy summertime precipitation while the third - the Sparkplug Canyon flow - was evidently triggered by high snowmelt runoff; the circumstances, as detailed earlier in this report, were somewhat special. The Sparkplug Canyon debris flow demonstrated that snowmelt runoff in even a small drainage system can provide sufficient water, if dammed for any great length of time, to bring about significant morphologic change and to represent a real threat to man and his works. Occasional landslide damming of meltwater-swollen streams has been reported in the past, but never to my knowledge had a bona fide debris flow developed in conjunction with snowmelt flooding, at least not in the White Mountains within the past 100 years. This flooding event, then, represents a possibility not foreseen 10 years ago.

Other episodes of snowmelt flooding, particularly those in drainages that have suffered major debris flows in recent decades, appear to have been remarkably similar from year to year. The "sponge" effect, so-called, of valley-floor alluvium and colluvium has operated to reduce the impact of excessive snowmelt in most White Mountains stream systems. Only those canyons lacking unconsolidated fill on trunk canyon floors have undergone extreme variations in discharge during periods of active snowmelt; most drainages have responded only slightly to heavy runoff, cresting slowly and returning to normal discharge equally slowly.

Wintertime flooding in December 1966, although apparently much more severe than other recent cold-season floods, did not differ radically in terms of cause and effect. Excessive rains at lower elevations were accompanied by heavy snowfall above 6,500 feet, and most runoff originated on or near valley floors. The greatest damage to man-made features was in the lowlands, as in the past, and terrain above an elevation of about 6,500 feet was essentially unaffected morphologically, since solid rather than liquid precipitation was falling there. In all probability, if temperatures during the period of heavy precipitation had been a few degrees higher or lower, flooding would have been considerably more destructive, especially in the White Mountains where morphologic effects in December 1966 were relatively minor.

Finally, cloudburst flooding during the last decade has produced morphologic effects and damage to man-made features very much like those suggested by the historical record and physiographic evidence of past inundations. Floods of the high-water type and the two debris flows generated by thunderstorm precipitation were guided in their courses

across alluvial fans by the location on them of active channels. Cloudburst flooding of the high-water type has occurred at least once in Lone Tree and Milner creeks during the last 10 years, whereas adjacent drainage systems that appear to have received similar amounts of rain yielded no excessive discharge. The effect of lack of valley-floor fill on runoff is thus seen to be operative during summer thunderstorms as well as during periods of snowmelt. From man's standpoint, drainage systems with "clean" trunk canyon floors are dangerous throughout the year, although they are most unlikely to produce major debris flows.

In one respect, at least, cloudburst flooding during the summer of 1967 differed from similar episodes in the past: the geographical distribution of the most serious floods was not exactly what would have been expected from a study of the historical record. The heaviest recorded rains fell south of the highest part of the range, with high runoff coming from drainage systems that appear to have undergone major flooding rather infrequently during the past 100 years. But in all cases the behavior of flood waters in trunk canyons and on alluvial fans was similar to that observed in the past in other parts of the mountains.

The use of recording rain gages during the summer of 1967 permits informed speculation about precipitation intensities necessary to produce floods of varying severity. The record contains evidence that rainfall intensities of several inches per hour have been fairly common in and near the White Mountains (Kesseli and Beaty, 1959, p. 23-24). Intensities of 1 inch/hour or greater were accurately measured during summer 1967; yet in no case did a true debris flow develop. It is therefore concluded that in the White Mountains - and presumably in other comparable desert ranges - it takes at least 1 to 2 hours of heavy rain with an intensity that exceeds 1 inch/hour to produce significant summertime floods. It is further believed that an intensity of <u>at least</u> 2 to 3 inches/hour is necessary before debris flows will be generated. Exceptions to these generalizations obviously would exist: (1) Precipitation of lesser intensity falling during a period of rapid snowmelt might very well result in serious flooding; (2) precipitation of lesser intensity after several days of more gentle rainfall could also produce dangerous flooding, since a prolonged, gentle rain would effectively saturate surface soils and thereby contribute to heavy overland flow. But on the basis of observations made during the summer of 1967, it seems probable that major floods with accompanying debris flows will not occur unless precipitation intensity exceeds 2 to 3 inches/hour.

3. <u>Drainage systems that did not flood during the period 1957-67.</u>

Of equal interest to this study is a consideration of those stream systems in the White Mountains that appear <u>not</u> to have undergone significant flooding in the period 1957-67. In many ways, these drainages could be more valuable to anyone trying to devise useful principles of site safety than are those which have sustained frequent floods and debris flows.

Field study in 1956-57 clearly indicated that the most dangerous drainage systems in the White Mountains are characterized by very distinctive morphologic features: they have steep and narrow trunk canyons with 5 to 15 feet of unconsolidated alluvial and colluvial fill on the floors, and they tend to head in the highest parts of the range. They have been designated in this and the earlier study as having the Falls Canyon profile type. Conversely, relatively "safe" drainages also possess specific morphologic characteristics: their trunk-canyon profiles are much gentler, they tend to be considerably wider, especially in the lowermost segment of the canyon, many of them are deeply alluviated, and most of them head along lower parts of the crest of the range. Canyons of this sort are considered to be of the Middle Creek type. Not all of the stream systems of the White Mountains will fit into one or the other category, but most of them will.

The flooding history of the past 10 years in the White Mountains, with only a few exceptions, testifies remarkably well to the validity of the generalizations stated above. That is to say, much of the higher-than-normal runoff during this time came from drainages characterized by a morphology judged to be favorable for the occurrence of major floods, while most of the more gentle canyons seem to have undergone virtually no high discharge.

Other things being equal, it seems probable that the shape of the long profile of the trunk canyon in a desert stream system is the single most important morphologic characteristic affecting its flooding potential. Granting that other things rarely are equal, it is nonetheless the case that White Mountains drainages with the Middle Creek trunk profile type have, in general, been free of major floods, not only during the last decade but for all of the historical period as well. The morphologic characteristics of canyons of the Middle Creek type all militate against the development of larger floods and debris flows that might reach and cross alluvial fans. The relatively gentle gradients of lower canyon floors assure that water or mobile debris surging down from steeper slopes will undergo a loss of velocity and momentum well above the canyon mouths. Deep alluvial and colluvial fill in the lower segments of canyons can effectively absorb surface runoff from steep upper canyon floors and tributary slopes, thus favoring a gradual rather than sudden release of high discharge. The lower trunk canyons in most drainage systems of the Middle Creek type are wide enough so that temporary damming of mobile debris is unlikely, and fluid rubble that does reach canyon mouths is more apt to be released to the fan surface at a slow, continuous rate than in a series of surges or waves. In short, if a debris flow does develop high in a drainage basin of the Middle Creek type, it is much more likely to be stopped or slowed in a broad lower canyon with gentle gradient, where spreading and loss of momentum may occur, than in a steep, narrow bedrock channel in which the coherence of the fluid mass can be maintained to the canyon mouth. Major floods of the high-water type would also be similarly affected.

It is perhaps not surprising, then, that many White Mountains drainage systems of the Middle Creek type show little evidence of flooding activity over the last 10 or, for that matter, 100 years. Yet at least some of the more gentle canyons have experienced recent floods, several during the heavy rains of early December 1966, a few during the period of thunderstorm activity in July 1967. Silver Canyon, Poleta Canyon, and Black Canyon sustained high runoff in December 1966; Leidy Creek and Black Canyon had cloudburst floods of the high-water type in July 1967. However, in none of these instances of flooding was discharge sufficiently great to generate a true debris flow, even though in all of them significant volumes of coarse rubble were moved in active channels in canyons and on alluvial fans.

But the generalizations proposed as a result of observations made during the 1956-57 study seem, in the main, to have been confirmed by the flooding experience of the past 10 years and are considered to be still valid. Despite some conspicuous exceptions, most of the White Mountains drainage systems of the Middle Creek type were not affected by flooding in the past 10 years.

4. Re-evaluation of site safety

It is believed that the principles of site safety enumerated in the study of 1956-57 are applicable to any future consideration of land use in mountainous desert terrain. Flooding events during the decade 1957-66 and the current period of field study have not been sufficiently different in terms of intensity or behavior seriously to alter previously established conclusions.

a. Canyons

Canyons in desert ranges present limited opportunities for land use of any sort and almost without exception should be considered dangerous sites, even those with comparatively wide floors. In the event that use of a canyon cannot be avoided, roads, structures, or any other man-made features should be placed as far above the floor of the canyon as is feasible. Structures that must be located on a canyon floor proper should be regarded as temporary, since even a moderate flood, particularly in a narrow canyon, could be destructive. If permanent installation of a road is contemplated in a canyon of a desert range, either the roadway should be constructed well above the canyon floor, or it must be anticipated that inevitably parts of the road will be flooded or perhaps completely destroyed; this is only a matter of time.

b. Alluvial fans and bajadas

Alluvial fans and bajadas present a much wider choice of possibilities for land use. The study of 10 years ago clearly indicated that on the typical fan a radial zone, flanking and including the active channel, is

potentially the most dangerous part of the surface. The depth to which the active channel on a fan has been cut is a factor of major importance in considering flooding danger, since high-water floods and debris flows tend to stay in or to be guided by deeply incised active channels in their courses across the surface. All of the White Mountains floods and debris flows during the period 1957-67 followed or remained close to active channels over most of their extent on the fans. Yet many debris flows of the past have spilled from active channels near the apexes of some White Mountains alluvial fans, and the danger is ever present that temporary damming of channels could produce similar results in the future. It is probable, however, that channels cut to a depth of 10 feet or more near apexes will successfully contain most floods and debris flows, at least on the upper parts of the fan surface. Spreading of debris flows and spilling out of channels of high-water floods have in the past commonly taken place on the middle and lower surfaces of White Mountains fans. Such spreading and spilling out have occurred most often where active channels shallow to depths of 5 feet or less. Local sheet flooding has occasionally been observed on the lower margins of some alluvial fans in the White Mountains region, but depths of water in sheet floods have been slight, generally less than a foot, and the areas thus affected have been limited.

It is concluded that the evaluation of relative site safety on alluvial fans developed as a result of the study of 1956-57 remains valid. Figure 55, reproduced from Kesseli and Beaty's report of 1959 (p. 97), shows areas of comparative flooding danger on a typical desert fan. Land use, including road construction, should be undertaken on alluvial fans and bajadas with the indicated zones of relative safety and danger clearly in mind.

c. Rain gage installation in areas of land use

It would seem prudent to place one or more rain gages in a desert highland above an area on a fan or bajada for which permanent use is planned. This would be especially desirable if major drainage systems were located adjacent to an area of contemplated use. Although it is probably not possible to predict accurately the occurrence in time and place of a potentially flood-producing rain, data on the intensity and duration of precipitation while it is falling could be of great value in estimating the possible effects of a heavy downpour. Should an intensity of 2 or 3 inches per hour be reached or exceeded, the chances would be great that a major flood, and possibly a debris flow, was impending, and at least some advance warning would thus be available. Taking a simple precaution of this sort might result in the saving of lives and material that would otherwise be lost; at the very least, it could permit removal of vehicles and other portable equipment to positions of safety.

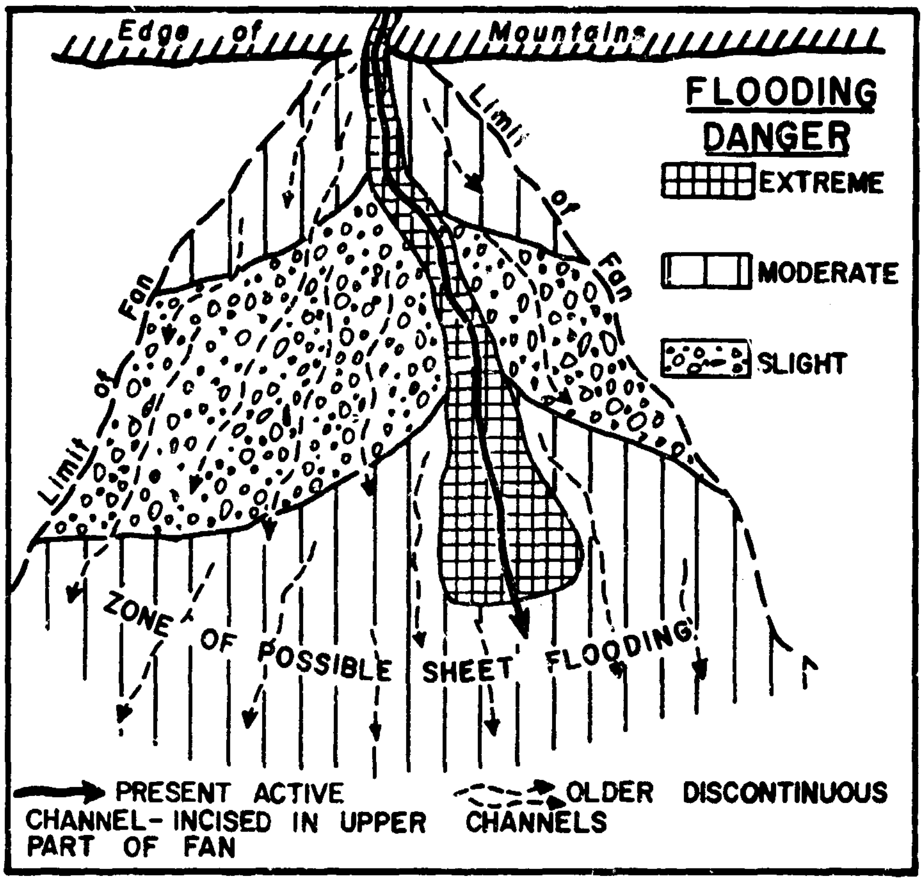


Figure 55. Diagramatic sketch showing areas of comparative flooding danger on a typical White Mountains alluvial fan.

5. Application of study to other areas

It was concluded in the study of 10 years ago that although the White Mountains may differ in detail from other high desert ranges, there are sufficient similarities in climatologic and morphologic characteristics so that general principles of flooding there established ought to be widely applicable in the mountainous deserts of the earth (Kesseli and Beaty, 1959, p. 100-101). These principles are:

a. The relative safety of different parts of an alluvial fan should be approximately the same on fans fringing any desert mountain range. The most dangerous part of any fan is a strip flanking and including the active channel which extends downslope below the point at which shallowing of the active channel occurs.

b. The profile, width, and depth of alluviation of the trunk canyon of a desert stream system are important morphologic characteristics determining the flood hazard and probable type of flooding. The more nearly the trunk canyon resembles a steep, narrow bedrock flume, the greater will be the flooding hazard; in addition, if such a canyon has unconsolidated alluvium on its floor, the possibility of the development of a serious debris flow will be definitely increased.

c. A direct correlation exists between steepness of fan slope and danger of major floods from the canyon above the fan; thus, steep fans are a first, easily recognizable indicator of the possibility of serious floods, while more gentle fans suggest a lower flooding hazard.

d. The radial channel pattern on many White Mountains alluvial fans insures that debris and water spilling out of active channels during floods will follow divergent paths and thus lose part of their momentum and potentially destructive energy. A similar result can be anticipated in other areas with fans on which a radial pattern of channels is evident.

e. The thunderstorm season, summer, is the period of greatest flooding danger in the White Mountains. Presumably this is true elsewhere; that is, greatest flooding frequency would prevail during that part of the year in which thunderstorms normally occur. For most deserts of the world these occur in the summer season.

f. The influence of man-made dikes and ditches on alluvial surfaces has been shown to be significant in bringing about a concentration of runoff into larger channels, in which it acquires increased volume and velocity and thus increased potentially destructive energy. This influence should be active on any alluvial surface on which natural runoff in channels of its own making is diverted to artificial channels by a system of dikes and ditches.

Flooding in the White Mountains during the past 10 years has produced no evidence that these general principles should be modified.

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APPENDIX

PRECIPITATION IN STUDY AREA DURING CONTRACT PERIOD (SEPT 66 - AUG 67)

Assembled in this Appendix (Table II) are monthly records of precipitation for U. S. Weather Bureau stations in and immediately adjacent to the study area, and for the sites at which rain gages were installed during the investigation. Rain gage locations are shown on the fold-out map at the end of the report.

During the contract period non-recording rain gages were shifted when weather changes made some locations inaccessible. Thus, not all the sites indicated were operational at the same time. Recording rain gages were placed at the Mount Barcroft laboratory, Crooked Creek laboratory, and Schulman Grove (near Reed Flat) during July and August 1967 and were maintained by station personnel. The Schulman Grove locality was chosen because the Inyo National Forest has a ranger-naturalist on duty there during the summer months and thus someone was available to look after the equipment. Total precipitation for the 12-month period from 1 September 1966 to 31 August 1967 is indicated for the U. S. Weather Bureau stations in Table II. For comparison, annual averages at five of the seven Weather Bureau stations are also shown (as given in Table I); the stations at Montgomery Pass and Benton Inspection Station have been in operation for only a few years, and therefore no average values are available for them.

As the records clearly show, the study period was one of considerably greater-than-average precipitation in the White Mountains area. Two particularly wet periods stand out: December 1966 and July-August 1967. It was primarily heavy precipitation at these times that boosted the totals at the Weather Bureau stations to well above the long-time means for the 12-month period. The most significant flooding of the contract period occurred during these periods. April 1967 was also a wet month, especially along the crest of the White Mountains, and the moderate snowmelt flooding of May and June 1967 resulted in part, at least, from runoff generated by the melting of the April snows in the higher parts of the range.

TABLE II

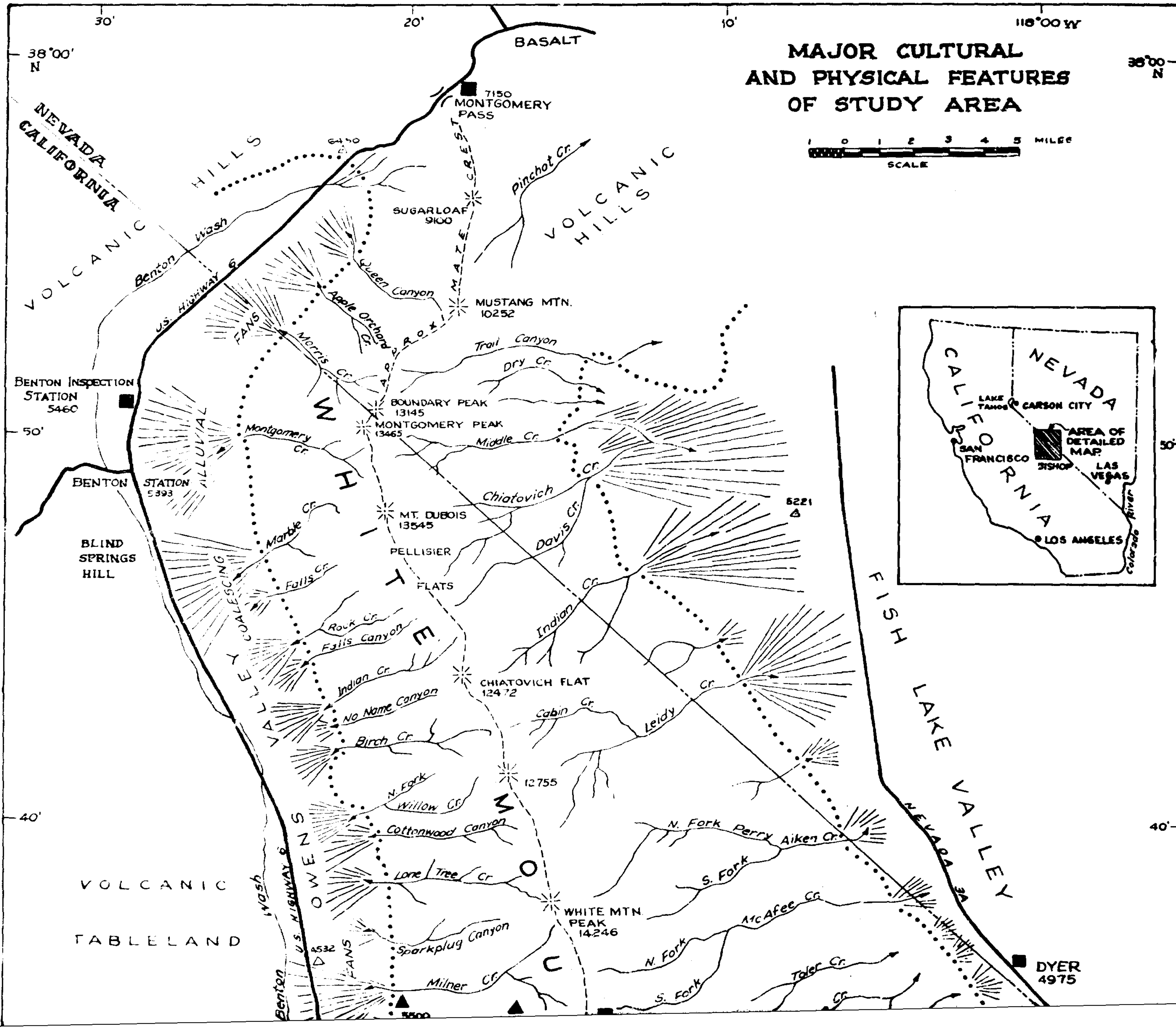
Precipitation during Contract Period (September 1966 through August 1967)

Station and Elevation	1966 Sep	Oct	Nov	Dec	1967 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total	Av.
*Bishop 4,108	.18	0	.27	5.79	1.64	T	.50	.47	.02	T	.62	.03	9.52	5.84
Montgomery Pass 7,150	.97	0	.03	1.83	2.03	.20	.60	2.95	.47	.32	2.74	.54	12.68	**
*Dyer 4,975	.95	0	.20	1.62	.42	T	.51	1.28	.01	T	1.39	.02	6.40	3.22
*Deep Springs School 5,225	.48	0	.08	3.62	2.14	T	.03	1.80	.16	.05	1.12	.35	9.83	5.45
Benton Inspect. Sta. 5,460	.19	0	.55	6.43	1.88	.08	.15	.51	.26	.24	1.32	.46	12.07	**
*White Mountain I 10,150	.09	.03	1.21	7.25	3.65	.36	.60	2.21	.33	.15	4.02	2.30	22.20	12.54
*White Mountain II 12,470	.06	0	.19	8.50	5.75	.90	2.60	3.25	.49	.73	4.50	1.89	28.86	15.54
Silver Can. 4,500		0	.26	5.43	1.49	.02	.44	.51	.02	T	.32	.42		
Silver Can. 7,000		0	.46	6.07	2.06	.14	.60	1.83	.21	.06	1.83	.68		
Silver Can. 9,000		0	.63							.13	2.30	1.85		
Coldwater Can. 5,000		0	.25	4.81	1.31	.02	.35	.86	.06	.02	.52	.37		
Coldwater Can. 7,600										.09	1.59	1.88		
Milner Creek 5,500		0	.24	4.81	1.86	T	.19	1.46	.28	.06	.51	.87		
Milner Creek 9,000										.41	2.98	2.65		
Schulman Grove 10,100											3.83	1.44		

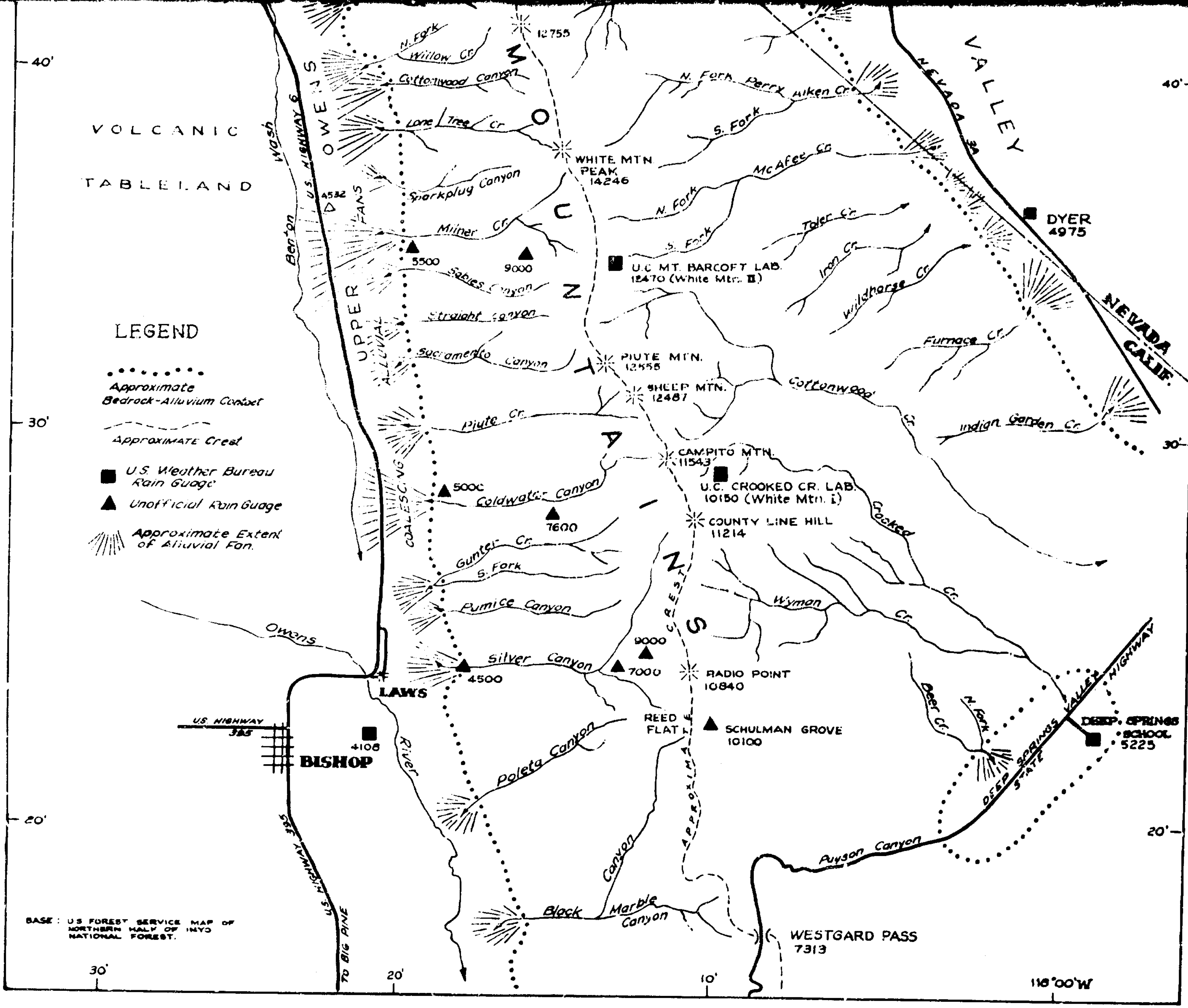
* For monthly averages see Table I

**Averages not established (stations not operating long enough)

A.



MAJOR CULTURAL AND PHYSICAL FEATURES OF STUDY AREA
0 1 2 3 4 5 MILES
SCALE
30'
20'
10'
118°00'W
38°00' N
50'
40'
BASALT
7150 MONTGOMERY PASS
NEVADA
CALIFORNIA
HILLS
VOLCANIC HILLS
VOLCANIC
SUGARLOAF 9100
APPROX MATE CREST
Pinchot Cr.
MUSTANG MTN. 10252
Benton Wash
U.S. HIGHWAY 6
Queen Canyon
Apple Orchard Cr.
FANS
Morris Cr.
Trail Canyon
Dry Cr.
BENTON INSPECTION STATION 5460
BOUNDARY PEAK 13145
MONTGOMERY PEAK 13465
Montgomery Cr.
Middle Cr.
ALLUVIAL
BENTON
STATION 5393
WHITE MOUNTAINS
Chiatovich Cr.
MT. DUBOIS 13545
Davis Cr.
5221
Marble Cr.
PELLISIER FLATS
BLIND SPRINGS HILL
COALESCING
Falls Cr.
Indian Cr.
Rock Cr.
Falls Canyon
CHIATOVICH FLAT 12472
Indian Cr.
No Name Canyon
Cabin Cr.
Leidy Cr.
Birch Cr.
VALLEY
12755
N. Fork
Willow Cr.
OWENS
Cottonwood Canyon
N. Fork Perry Aiken Cr.
FISH LAKE VALLEY
Lone Tree Cr.
S. Fork
VOLCANIC
TABLELAND
Wash
WHITE MTN. PEAK 14246
McAfee Cr.
NEVADA 3A
Sparkplug Canyon
4532
FANS
N. Fork
DYER 4975
Milner Cr.
Toler Cr.
Cr.
S. Fork
Benton
5500
NEVADA
CALIFORNIA
LAKE TAHOE
CARSON CITY
AREA OF DETAILED MAP
SAN FRANCISCO
BISHOP
LAS VEGAS
Colorado River
LOS ANGELES



VOLCANIC TABLELAND
OWENS VALLEY
WHITE MOUNTAINS
UPPER COALESCING ALLUVIAL FANS
NEVADA
CALIF.
NEVADA 3A
U.S. HIGHWAY 6
U.S. HIGHWAY 395
TO BIG PINE
DEEP SPRINGS VALLEY HIGHWAY
DEEP SPRINGS STATE
DYER 4975
DEEP SPRINGS SCHOOL 5225
WHITE MTN PEAK 14246
12755
U.C. MT. BARCOFT LAB. 12470 (White Mtn. II)
PIUTE MTN. 12558
SHEEP MTN. 12487
CAMPITO MTN. 11543
U.C. CROOKED CR. LAB. 10150 (White Mtn. I)
COUNTY LINE HILL 11214
RADIO POINT 10840
SCHULMAN GROVE 10100
REED FLAT
WESTGARD PASS 7313
APPROXIMATE CREST
LAWS
BISHOP
4108
4532
5500
9000
5000
7600
4500
7000
Benton Wash
Owens River
N. Fork
Willow Cr.
Cottonwood Canyon
Lone Tree Cr.
Sparkplug Canyon
Milner Cr.
Sabies Canyon
Straight Canyon
Sacramento Canyon
Piute Cr.
Coldwater Canyon
Gunter Cr.
S. Fork
Pumice Canyon
Silver Canyon
Poleta Canyon
Black Canyon
Marble Canyon
N. Fork Perry Aiken Cr.
S. Fork
McAfee Cr.
N. Fork
S. Fork
Toler Cr.
Iron Cr.
Wildhorse Cr.
Furnace Cr.
Cottonwood Cr.
Indian Garden Cr.
Crooked Cr.
Wyman Cr.
Beer Cr.
N. Fork
Payson Canyon
LEGEND
Approximate Bedrock-Alluvium Contact
Approximate Crest
U.S. Weather Bureau Rain Guage
Unofficial Rain Guage
Approximate Extent of Alluvial Fan.
BASE: U.S. FOREST SERVICE MAP OF NORTHERN HALF OF INYO NATIONAL FOREST.
40'
30'
20'
10'
118°00'W

B.

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13. ABSTRACT

A field study of flood conditions in the White Mountains of California and Nevada was carried out during the period September 1966 to August 1967. The investigation was a follow-up to a similar study conducted in 1956-57.

Flooding during the decade 1957-66 has produced significant changes in parts of the White Mountain landscape. One minor and two major debris flows occurred during the period, and minor snowmelt flooding was frequent.

Flooding observed during the contract period was of the three types known to occur in the study area: wintertime, snowmelt, and cloudburst floods. Floods were observed in December 1966, May-June 1967, and July-August 1967. No debris flows developed during any of the episodes of flooding.

In the study of 1956-57 it was found that three physiographic characteristics influence flooding behavior in a desert stream system: (1) trunk canyon profile; (2) amount of debris on floor of trunk canyon; and (3) width of lower canyon and canyon mouth. It was concluded that the most dangerous canyons are steep, narrow, and floored with 5 to 15 feet of unconsolidated debris. The area of greatest flooding danger on a desert alluvial fan is a radial zone extending from the apex toward the margin and flanking and including the active channel. The upper and lower thirds of a fan were found to be moderately dangerous, and the middle third is subject to only slight flood danger.

The observed and reconstructed behavior of floods in and near the White Mountains during the period 1957-66 was in accord with the indicated principles, and it is concluded that these principles are valid.

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Deserts	9		9		9	
White Mountains, California	9		9		9	
Flow	7		8		7	
Debris	7		9		6,7	
Physiography					6	
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